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THE MINERAL MATTER OF THE SEA, WITH SOME SPECULATIONS AS TO THE CHANGES WHICH HAVE BEEN INVOLVED IN ITS PRODUCTION

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It has been calculated that if the salt now in the sea were precipitated, it would make something like 3,500,000 cubic miles. If to this be added all the other mineral matter in solution in the sea water, the amount would be swollen to about 4,500,000 cubic miles.[1] This amount of mineral matter is equal in amount to nearly one-fifth of all the material in all lands above the sea at the present time; that is, equal to all the material in North America, Europe, and Australia, and most of the islands of the sea. If the mineral matter of the sea were precipitated on the ocean bottom, it would make a layer about 175 feet deep. If it were precipitated and concentrated in the shallow water of the ocean about the borders of the continents, building up the bottom to sea-level, this amount of mineral matter would add something like 19,000,000 square miles to the land—an area equal to about one-third that of all existing land. Most of this mineral matter in solution in the sea has probably come from the rocks of the land and of the sea bottom, chiefly the former.

Amount of mineral matter extracted from the sea.—These figures may perhaps give some idea of the amount of mineral matter in solution in the sea, but they give no more than a hint of the importance

[1] *Scottish Geographical Magazine*, Vol. XXI, p. 133.

of the solvent work of water, for most mineral matters carried to the sea in solution by rivers are extracted from the water about as rapidly as they are supplied. It is probable, indeed, that the amount of mineral matter which has been extracted from the sea water far exceeds all that remains in solution. This conclusion may be reached either (1) by calculating the volume of rock material which has been extracted from the sea water, or (2) by comparing the proportions of the various sorts of mineral matter in sea and in river water.

1. The rock matter extracted from the sea includes most of the limestone, the gypsum, and the salt, and much of the cementing material of all other sorts of sedimentary rock. Data concerning the thickness of such materials beneath the sea are not available, but some calculations concerning their average thickness in land areas, most of which have been beneath the sea at times, have been made. Dana estimated the average thickness of limestone (presumably for the continents) at about 1,000 feet.[1] This figure appears to take no account of the calcium carbonate which forms an important constituent of many shales and some sandstones, and it is not clear whether it was meant to include dolomites.

Reade estimates the thickness of the limestones for the globe (not for the continents merely) at about 528 feet;[2] but this figure, like the preceding, appears to take no account of the calcium carbonate in the sandstones and shales.

Van Hise, attempting to underestimate rather than overestimate, assigns a thickness of 328 feet to the limestones of the continents in the zone of katamorphism, and estimates that about an equal amount of calcium carbonate exists in the shales and sandstones.[3] This gives an aggregate of 656 feet of calcium carbonate for the continents above the zone of anamorphism.

If the estimates of Dana and Reade be increased to make allowance for the calcium carbonate in the shales and sandstones, and if the estimate of Van Hise be increased to include the limestones below

[1] Dana, *Manual of Geology*, 4th ed., p. 485.

[2] T. Mellard Reade, *Chemical Denudation in Relation to Geological Time* (London, 1879), p. 53.

[3] *Monograph 47*, U. S. Geological Survey, pp. 940, 941.

the zone of katamorphism—and limestone is known to exist there—all the above figures will be increased.

No careful estimate of the amount of limestone beneath the sea is possible, but its amount must be great. It probably forms a larger proportion of the sediment than on land, but it does not follow that its average thickness is greater. If we assume that the average thickness of limestone beneath the sea is half as great as that on the land, and that the amount of calcium carbonate in other sedimentary rocks beneath the sea is, on the average, half as great per square mile as on land, we may derive from the figures representing the estimated thickness of limestone material on the continents, figures representing an estimated average for the earth. These figures are 420 (based on the estimate of Van Hise) and 850 feet (based on the estimate of Dana). The estimate of Reade, increased to allow for the calcium carbonate in clastic rocks, becomes 738 feet.

Even if these large figures be correct, they represent less than the total amount of mineral matter which has been extracted from the sea, since they deal with one sort of mineral matter only. How much they should be increased to include all the mineral matter ever extracted from the waters of the sea cannot be stated; but the silica, the various sulphides and sulphates, the chlorides, etc., which have been extracted from the sea water, would swell them appreciably.

Much material, such as that of limestone, has been extracted from the sea water and deposited, and then re-dissolved, re-extracted, and re-deposited. Some material, indeed, has probably gone through this cycle many times. The aggregate result of the solvent work of water is therefore not represented by the amount of existing rock matter which has been extracted from the sea, plus that which still remains in solution. Furthermore, the considerations adduced take no account of the deposition of material from solution on the surface of the land, or beneath it, or in the lithosphere under the sea. The amount of mineral matter deposited from solution in these situations is certainly great, though it cannot well be estimated. It must, however, be recognized, in attempting to gain the proper conception of the solvent work of ground water.

2. By comparing the mineral matter in the sea water with that in average river water, Tables I and II, it is seen that calcium car-

bonate is about 20 times as abundant as sodium chloride in river water, but only $\frac{1}{225}$ as abundant in sea water. If the calcium carbonate which has been taken to the sea in solution by rivers had remained in solution as calcium carbonate in the same proportion that the sodium chloride has remained in the sea water, the figures representing the amount of common salt which the sea contains would seem almost insignificant in comparison. Even if calcium carbonate is changed to calcium sulphate in the sea, as is sometimes thought, the case is not seriously altered, for the amount of calcium sulphate in the sea is but a small fraction of the amount of sodium chloride. In order that the sodium chloride should have attained such predominance, it is necessary to suppose that enormous quantities of the compounds of calcium have been extracted, if the salt of the sea has been derived from the land.

The average river water contains about seven times as much magnesium carbonate as sodium chloride, four and a half times as much silica, twice as much calcium sulphate, twice as much sodium sulphate, more potassium sulphate, and more sodium nitrate; yet the combined volume of all these substances in the sea water is but a small fraction of the amount of sodium chloride.

By either of these lines [(1) and (2)] of approach, we reach the conclusion that the amount of mineral matter which the sea has lost from solution far exceeds that which it has held until the present time.

TABLE I

AMOUNT OF MINERAL MATTER IN SOLUTION IN ONE CUBIC MILE OF SEA WATER[1]

Constituents	Tons
Chloride of sodium ($NaCl$)	117,434,000
Chloride of magnesium ($MgCl_2$)	16,428,000
Sulphate of magnesium ($MgSO_4$)	7,154,000
Sulphate of calcium ($CaSO_4$)	5,437,000
Sulphate of potassium (K_2SO_4)	3,723,000
Bromide of magnesium ($MgBr_2$)	328,000
Carbonate of calcium ($CaCO_3$)	521,000
For sea water, total dissolved matter	151,025,000

[1] Dittmar, *Challenger Reports*, Physics and Chemistry, Vol. I, p. 204.

TABLE II

MINERAL MATTER IN SOLUTION IN ONE CUBIC MILE OF AVERAGE RIVER WATER[1]

Constituents	Tons
Calcium carbonate ($CaCO_3$)	326,710
Magnesium carbonate ($MgCO_3$)	112,870
Calcium phosphate ($Ca_3P_2O_8$)	2,913
Calcium-sulphate ($CaSO_4$)	34,361
Sodium sulphate (Na_2SO_4)	31,805
Potassium sulphate (K_2SO_4)	20,358
Sodium nitrate ($NaNO_3$)	26,800
Sodium chloride (NaCl)	16,657
Lithium chloride (LiCl)	2,462
Ammonium chloride (NH_4Cl)	1,030
Silica (SiO_2)	74,577
Ferric oxide (Fe_2O_3)	13,006
Alumina (Al_2O_3)	14,315
Manganese oxide (Mn_2O_3)	5,703
Organic matter	79,020
Total dissolved matter	762,587

Time necessary for the accumulation of the mineral matter of the sea.[2]—The discharge of water into the sea by rivers is estimated at 6,524 cubic miles per year.[3] This volume of water is estimated to carry to the sea 0.433 cubic miles of mineral matter in solution.[4] At this rate, it would take about 10,500,000 years for the streams to carry to the sea an amount of mineral matter equal to that which it now contains, and at this rate it would take about 54,000,000 years for an amount of mineral matter equal to all that is now above the sea, to be dissolved and carried to the oceans.

The sodium chloride makes up about 2.2 per cent. of the mineral matter in solution in river water. The same substance constitutes nearly 78 per cent. (77.758 per cent.) of the mineral matter in the sea water. The 2.2 per cent. of 0.433 cubic miles is 0.0095 of one cubic

[1] Murray, *Scottish Geographical Magazine*, Vol. III, p. 77.

[2] Most of the following computations have been made or verified by Messrs. J. H. Lees and E. W. Shaw.

[3] Murray, *op. cit.*, Vol. IV, p. 41.

[4] Murray, *loc. cit.*, states that the amount of mineral matter carried to the sea annually by rivers is 1.183 cubic miles; but the data on which this calculation is based (*op. cit.*, Vol. III, p. 76, 77) give only 0.433 cubic miles.

mile, which represents approximately the amount of salt brought to the sea per year by rivers, assuming that the specific gravity of salt is the same as the average specific gravity of the mineral matter in solution in the sea and rivers; while 77.758 per cent. of the total amount of mineral matter of the sea (4,532,110 cubic miles) is 3,524,078 cubic miles, the approximate amount of salt in solution in the sea water. This amount divided by 0.0095 is more than 370,000,000, which represents roughly the number of years it would take for the amount of salt now in the sea to have been brought to it by rivers, at the present rate.

This figure is, however, not to be taken as representing the age of the sea. There are several reasons for avoiding this conclusion. These are as follows: (1) The rate at which salt has been brought in by rivers has probably not been constant; (2) the salt may have been derived partly from sources other than land waters; and (3) much salt has been extracted from the sea water and deposited. The second and third points tend to offset each other. In spite of the limitations imposed by these considerations, the figure 370,000,000 may give some conception of the order of magnitude of the number which expresses the age of the sea in years.[1]

The calcium carbonate carried to the sea by rivers in solution, at the present time constitutes, according to Table II, nearly 43 per cent. of all the mineral matter taken to the sea in solution. Its amount is therefore about one-fifth of a cubic mile per year. The calcium carbonate now in solution in sea water represents but 0.00345 of the mineral matter which the sea contains. This fraction of 4,532,110 cubic miles is about 15,635 cubic miles, which represents, approximately, the amount of calcium carbonate now in solution in the sea. If this substance is carried to the sea at the rate of one-fifth of a cubic mile per year, it would take only about 84,000 years for the amount now in solution in the sea to be brought down from the land. If the calcium sulphate of the sea water has been derived partly from the calcium carbonate brought to the sea, this

[1] Professor Joly has calculated, from the salt of the sea, that the time since the ocean began to receive solutions from the land may be 90 to 100 millions of years. He assigns 10 per cent. of the sodium chloride of the rivers to atmospheric sources. (*Transactions of the Royal Society of Dublin*, Vol. VII (Series 11), 1899, p. 23, and *Geological Magazine*, 1900, p. 220.)

period of 84,000 years should be lengthened. Treating calcium carbonate and calcium sulphate as one, it would take the rivers about 740,000 years to contribute what the sea now contains.

The reason for the great discrepancy between these figures and those which represent the time necessary for the accumulation of the salt of the sea, is doubtless found in the fact that the calcium compounds are extracted by the organisms of the sea, to make shells, tests, etc., about as fast as they are brought in, while the salt remains in solution.

The amount of calcium carbonate which may have been in solution in the sea.—The amount of calcium carbonate which would have been carried to the sea by rivers in 370,000,000 years, at the rate at which rivers are now contributing it, is about 68,600,000 cubic miles. In the same time the rivers should, at their present rate, have contributed about 7,200,000 cubic miles of calcium sulphate, or nearly 76,000,000 cubic miles of calcium carbonate and calcium sulphate. Since not more than about 179,000 cubic miles of calcium compounds (carbonates and sulphates) remain in solution in the sea at the present time, it will be seen that an enormous amount must have been extracted.

Most of the calcium deposited in the sea has been deposited in the form of calcium carbonate. If an amount of calcium carbonate and calcium sulphate corresponding to the difference between 76,000,000 and 179,000 cubic miles has been deposited, it would make a layer about 1,920 feet thick over the entire earth. Since, however, some of the calcium carbonate taken in solution to the sea has been redissolved, some of it repeatedly, after precipitation, the average thickness of that which has been deposited must be much less than 1,920 feet. Perhaps this figure should be reduced by one-half on this account.

Sixty-eight million six hundred thousand cubic miles, it may be noted, is about three times the cubic contents of all lands. Assuming that rivers have been supplying calcium carbonate and sodium chloride to the sea at the present rate, and assuming that the land has been the only source of these materials in the sea, it follows that the rivers should have carried to the sea an amount of calcium carbonate equivalent to about three times the cubic contents of all exist-

ing land, during the time necessary for furnishing the salt, at the present rate. If some of the salt has been derived from the lithosphere beneath the sea, the figures should be correspondingly reduced, though it is probable that the land has furnished much more salt than the sea bottom has. The reduction on this account is, in some measure, or perhaps altogether, offset by the allowance which should be made in the opposite direction for the salt which has been deposited among the sedimentary rocks of the earth.

Amount of average rock decomposed.—From the amount of salt in the sea, and from the amount of calcium carbonate which the sea is estimated to have had, calculations may be made as to the amount of average rock which must have been destroyed to produce them.

1. The average composition of accessible non-sedimentary rocks has been determined, probably with a fair degree of accuracy.[1] Knowing the percentage of sodium in this average rock, the volume of rock which must have been decomposed in order to furnish the sodium necessary to make the salt of the sea may be calculated. The average rock contains about 2.53 per cent. of sodium, and of rock containing this amount of sodium nearly 55,000,000 cubic miles would need to be decomposed, to yield enough sodium to form the salt now in the sea. The salt of the sea, therefore, seems to imply the decomposition of some such quantity of average rock. Since only about 23,500,000 cubic miles of rock now remain above sea-level,[2] and since much of this is sedimentary rock derived from the original rock, and since much of the non-sedimentary rock is not decayed, and still holds its sodium, it would appear that the larger part of the 55,000,000 cubic miles of rock necessary to yield the requisite amount of sodium must have been removed from the land to the sea.

2. A similar line of inquiry may be based on the amount of calcium carbonate which the sea has had in solution. The average rock contains about 4.90 per cent. of CaO.[3] On p. 471 the figures 420, 738, and 850 feet were deduced as perhaps representing, as well as they are now known, the limiting average thicknesses of limestone material for the earth. The largest of these figures is about twice

[1] F. W. Clark, *Bulletins 168* and *228*, U. S. Geological Survey.

[2] Murray, *op. cit.*, Vol. IV, p. 40. [3] Clark, *op. cit.*

the smallest. For convenience of calculation, and in view of the somewhat uncertain nature of the data on which they are based, no further error of great magnitude will be involved if the smallest of these figures be regarded as half of the largest, that is, 425.

If 425 and 850 feet be assumed to represent the maximum and minimum average thickness of limestone material, as nearly as it is now known, and if four-fifths of this be assumed to be calcium carbonate,[1] the amounts of calcium carbonate in the earth's crust would be equivalent to nearly 12,700,000 cubic miles in the one case, and to 25,400,000 cubic miles in the other. These figures are much smaller than that given on p. 475, but that includes the calcium carbonate re-dissolved, and carried anew to the sea, after being once deposited. These do not.

The amounts of average rock the decomposition of which would be needed to yield the amount of calcium necessary for these amounts of calcium carbonate, supposing all the calcium to be separated so as to be available for union with carbonic acid gas, would be 145,000,000 cubic miles and 290,000,000 cubic miles, respectively. These results, it will be seen, are about 2.6 and 5.2 times as large, respectively, as those derived from the calculation based on salt of the sea. Even after allowance is made for the salt which has been deposited, the figures are far apart. This means that some of the sodium does not unite with chlorine to produce salt, or that more of the sodium chloride has been deposited than is known, or that there is some other discrepancy in the data. In spite of the discrepancy, however, it will be noted that the figures belong to the same order of magnitude.

The same problem may be approached in another way. We have seen that the amount of calcium carbonate which should have been carried to the sea in the time necessary for the accumulation of the salt, assuming all of the latter to have come from the land, and at the present rate, is more than 68,000,000 cubic miles, and, if the calcium sulphate be added, about 76,000,000 cubic miles. To yield the calcium called for by these volumes, the decomposition of about 777,000,000 cubic miles of average rock would be necessary, if the calcium carbonate only is taken into consideration, and more than 60,000,000

[1] The rest being magnesium carbonate. Clark, *Bulletin 228*, U. S. Geological Survey, pp. 20, 21.

cubic miles more, if the calcium sulphate be included. Seven hundred and seventy-seven million cubic miles is more than 33 times the estimated cubic contents of the land, while 837,000,000 cubic miles (777,000,000 + 60,000,000) is about 36 times the estimated cubic contents of the land. These figures should be reduced to make allowance for the calcium carbonate which has been redissolved after having been precipitated. If half the calcium carbonate which the ocean water has had has been re-dissolved after having been once precipitated, the last figures should be divided by 2. Reduction should also be made for the calcium carbonate which has been derived from the rocks beneath the sea.

Assuming that 2 is the proper divisor, the amount of average igneous rock which must have been destroyed to produce the amount of calcium carbonate carried to the sea, at the present rate, in 370,000,000 years, is about 388,500,000 cubic miles, or, if calcium sulphate be included, 418,500,000 cubic miles. This amount of rock would make a layer more than 2 miles thick over the entire surface of the earth, and more than 6½ miles thick over the continents and continental shelves. This volume of mineral matter is about 18 times all that is now above the surface of the sea. These calculations, even though the figures involve a considerable error, indicate that an enormous body of rock must have been decomposed.

By both these methods of calculation, based on the calcium carbonate, it will be seen that the amount of average rock needed (pp. 476 and 477) to yield the estimated supply of calcium carbonate is considerably more than that needed to yield the known amount of salt. It is probable that salt furnishes the better basis for the estimates, since the amount which has been formed is probably more nearly known, most of it being presumed to still remain in the sea.

Even the above figures do not represent the full measure of transfer of the material from land to sea. In the decomposition which igneous rock undergoes, before yielding up its calcium in soluble form, it undergoes notable expansion. It follows that the preceding figures great as they are, may not represent the actual amount of average rock material destroyed, and removed from land to sea.

Assigning the average igneous rock a mineral constitution consistent with its chemical composition, its expansion on decomposition

may be estimated. The precise changes which such rock undergoes doubtless vary from point to point, and the degree of change before removal by erosion must also vary. It is probably safe to say that if the decomposition is measurably complete, the expansion in volume would be not less than an eighth, and it might be as much as a third. Let it be assumed to be one-fifth. The 55,000,000 cubic miles, the decomposition of which is called for to furnish the sodium necessary for the salt of the sea, would then become 66,000,000 cubic miles, and the 145,000,000 and the 290,000,000 cubic miles, the decomposition of which is called for to furnish the calculated amount of calcium carbonate, would become, respectively, about 174,000,000 and 348,000,000 cubic miles; while the 388,500,000 and 418,500,000 cubic miles (p. 479), increased by one-fifth, become about 466,000,000 and 502,000,000 cubic miles, respectively. These figures represent, respectively, about 3, 7, 14, 20, and 21 times the amount of material now above sea-level.

Since most of the decomposed rock is believed to have been in the land, and since but about 23,500,000 cubic miles now remain above sea-level, and this largely undecomposed, so far as it is non-sedimentary, it follows that an enormous body of rock material must have been removed from the land to the sea. If the rock so removed was not so completely decomposed as to yield up all its sodium and calcium, the total amount would have been greater than if decomposition were complete. When due allowance is made for the uncertainties of these figures, they are still so large as to give a magnified conception of the work which land waters may have done in the later stages of the earth's history. The transfer from land to sea of an amount of material equal to even 3 times all that that is now above the sea is most impressive. The transfer of an amount 21 times as great as that now above the sea, is still more stupendous.

3. The same general results may be approached in another way, though the calculation is based on somewhat speculative data. It has been estimated that the carbonic acid gas of the atmosphere is being consumed, in the original carbonation of rocks, at the rate of 270,000,000 tons per year.[1] On the assumption that four-fifths of this amount of carbonic acid gas goes to the carbonation of calcium

[1] Reade, cited by Chamberlin, *Journal of Geology*, Vol. VII, p. 682.

oxide,[1] the amount of calcium carbonate produced would be about 490,900,000 tons per year. This would make approximately $\frac{1}{2}\frac{1}{6}$ of a cubic mile. To furnish the amount of calcium oxide necessary for this amount of calcium carbonate, the decomposition of nearly one-half (0.44) a cubic mile of average rock would be required. In 370,000,000 years (p. 474) some 163,000,000 cubic miles of average rock would have been decomposed at this rate.

4. We are not obliged to rely on calculations based on somewhat unobtrusive changes, for our knowledge of the wasting away of the continents. Some conception of its importance may be gained in another way. The amount of sediment which streams carry to the sea each year has been calculated, with some approximation to accuracy. The amount of matter which they take to the sea from the land, including that carried in solution, as well as that carried mechanically, has been estimated as 3.7 cubic miles every year.[2] If this figure be modified to make allowance for the reduced volume in solution (p. 473), it becomes a little less than 3 cubic miles (2.93). Besides this loss to the lands through the erosion of the rivers, the winds blow great quantities of dust and sand into the sea every year, while the waves beat effectively on the coasts, cutting off, in the aggregate, enormous quantities of land material, and extending the dominion of the sea.

If rivers were to continue to wash away the continents at the present rate, they would remove to the sea an amount of material equal to all that is now above sea-level in less than 8,000,000 years, and the work of the winds and waves would shorten this period considerably.

If rivers have been wasting the land at the present rate for 370,000,000 years, they would have destroyed and carried away from the land about 58 times the amount of rock material now above sea-level. These figures take no account of the material blown from the land to the sea, nor of that worn from the shores by waves. If the work of these agents were taken into consideration, the figures given above would be notably increased. On the other hand, the

[1] F. W. Clark, has shown that the ratio of calcium oxide and magnesium oxide in 345 limestones analyzed is about $5\frac{1}{2}$ to 1. *Bulletin 228*, U. S. Geological Survey, pp. 20, 21.

[2] Murray, *op. cit.*, Vol. IV, p. 41.

present rate of river erosion is probably well above the average for the earth's history, since the lands are now relatively high.

5. There is still another way of approaching this problem. The sedimentary rocks of the continental areas are estimated to have a thickness, on the average, of something like a mile. No estimate of their average thickness in the sea is possible, but it is probably much less. If it be assumed to be one-fourth as great, the volume of sediment for the whole earth would be about 4 times that of the rock in all the lands of the earth. These figures, it will be seen, are near the least of those derived by the other modes of calculation (see p. 479).

Summary.—It appears, then, that we are to think of the decay and removal to the sea of an amount of rock equal to at least several times all that is now above the sea, during the course of the earth's history. The results of the several lines of calculation place the amount at 3 to 21 times all that is now above sea-level. The truth may lie between these extremes. So uncertain is the nature of the data, however, that we must recognize that the truth may lie outside of either, so far as present knowledge goes.

Renewal of the continents.—It is, of course, not to be inferred that the continents were ever large enough to include all the material which has been worn away from them, in addition to that which they now contain. They may never have been much larger than now, and they have certainly often been smaller. As their masses were reduced by erosion, they were renewed, either (1) by the sinking of the sea bottom, which drew the water off the areas which had been covered by shallow water only, or (2) by the rise of the continental areas. The former was probably the more common.

The renewal of the lands has not always kept pace with their reduction, so that the area of the lands and the amount of rock which they have contained, have fluctuated notably from time to time.

Effect of preceding changes on areas of sea and land.—Though great weight is not to be attached to the figures worked out on the basis of the assumptions made, it is believed not only that they are suggestive of the amounts of rock which have been worked over in the earth's history, but that they suggest lines of quantitative study which are worthy of attention. If, for example, a given amount of

rock has been removed from land to sea, the resulting change of sea-level may be calculated. If the bottom of the sea were not warped so as to increase or decrease the capacity of its basin, the transfer of 66,000,000 cubic miles of rock from land to sea would raise the level of the latter more than 2,400 feet,[1] if no allowance be made for the increased area resulting from the rise. The transfer of 174,000,000 cubic miles of rock from land to sea would raise its level more than 6,400 feet, while the transfer of 348,000,000 cubic miles would raise its level nearly 13,000 feet, or more than two and one-half miles, if its area remained constant. The increase of area which would be involved would, of course, reduce these figures sensibly.

If the sea-level were to rise 2,400 feet at the present time, about two-thirds of all the present land would be submerged, and if it were to rise 13,000 feet, only about 2 per cent. of the present land would remain above it. Even if allowance is made for the increase of area which its rise would produce, the transfer of 348,000,000 cubic miles of rock material to the sea would leave no vestige of land in North America east of the Rocky Mountains, and all that remained within the area of the western mountains would be a series of islands where the higher mountains now are. On the basis of even the least of these figures, 2,400 feet, reduced so as to make allowance for the increase of area which would be involved, there would be changes of relative level between sea and land, of an order commensurate with those which are known to have taken place from time to time during the earth's history.

There is reason to believe that the continents, at least those whose geological history is best known, have more than once been worn down toward sea-level—worn down so low that rivers became sluggish, and their mechanical erosion relatively slight. Such a condition would exist if the lands of the present time were worn down to an average height of 500 feet. In this case, about 5,000,000 cubic miles

[1] The materials taken to the sea in solution would not raise the level of the sea so much, cubic mile for cubic mile, as mechanical sediments. Since much the larger part of the sediment taken to the sea has been in the form of mechanical sediments, if we may judge from present conditions, this difference is here neglected; but it seems probable that the amount of dissolved matter has been greater than now, relative to the mechanical sediments, if the whole of the earth's history be considered.

of rock would remain above sea-level, while about 17,000,000 would have been removed. The deposition of 17,000,000 cubic miles of mineral matter in the sea would raise its level between 500 and 600 feet, and such a rise would submerge an area of about 12,000,000 square miles of the present land, or more than one-fifth of its area. Considering the much larger area which would be submerged by an equal rise of the sea-level when the lands had been lowered to the extent indicated, there would be a submergence of continents comparable to those which have repeatedly marked the beginnings and ends of geologic periods.

The facts (1) that the notable changes in relative level of land and sea have been periodic, and (2) that the sea-level seems to have been lowered at times, and not to have been continually rising, as it would be if affected by sedimentation alone, are probably to be accounted for by crustal warpings.

In so far as sedimentation has been a cause of subsidence of the ocean bed, the subsidence has probably lagged behind the sedimentation. In so far as the sinking of the sea bottom is independent of sedimentation, it is unlikely that it always, or even generally, kept pace with sedimentation. It would appear, therefore, that rise of the sea-level due to sedimentation may have been an important factor, or even, perhaps, a chief factor, in the submergence of the continents, at various periods in the earth's history, while the unequal rates at which sediment has been transferred from land to sea may have had an influence on the rate at which submergence was brought about. It is highly probable that crustal warpings, by increasing the capacity of ocean basins, have, on the whole, tended to reduce the amount of change of sea-level which sedimentation alone would have effected. Volcanic material extruded into the sea, on the other hand, has worked in the opposite direction.

Rate of change in relations of sea and land.—It is not to be supposed that such changes in the level of the sea as those mentioned on p. 482 have actually taken place as the result of sedimentation, for the ocean bed has probably been sinking through the ages, though perhaps not continuously, and probably not at a constant rate, even during periods of sinking. Subsidence of the ocean bottom would tend to counteract the effect of sedimentation, so far as its effect on

the level of the sea is concerned, for sinking of the bottom increases the capacity of the basin, just as the deposition of sediment in it decreases it. At those periods when sedimentation in the oceans exceeded subsidence of the ocean beds, the sea-level must have risen, and the lower parts of the continents must have been submerged. At those periods when subsidence of the ocean bed increased the capacity of the basin more rapidly than sedimentation decreased it, the water would have been drawn off the continental shelves, and lands would have emerged. It seems not improbable that this has been a main factor in bringing about repeatedly the submergences of great parts of the continental areas, in the course of geological history.[1] The periodic sinking of the continents bodily has doubtless also been a factor leading to the same result.

It is to be understood that all changes of sea-level, due to sedimentation and warping, have probably taken place very slowly—so slowly that their effects, in all probability, would not have been conspicuous to observers, had there been observers to witness them.

[1] The effectiveness of gradation (degradation and aggradation) in bringing about considerable submergences of land areas was first urged, so far as I am aware, by Professor Chamberlin.

THE CLASSIFICATION OF IGNEOUS INTRUSIVE BODIES[1]

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THE NEED FOR A CLASSIFICATION

At the present time geological science is engaged with no general question more widely and thoroughly discussed than that of the origin of the igneous rocks. The elaborate chemical studies of those rocks, the many new classifications of rock species, the modern experiments in the synthesis of natural silicates, and the experiments on the physical and chemical properties of molten silicates, have as their chief end the demonstration of the facts upon which a stable theory of rock genesis can be founded.

All such studies must be pursued with constant reference to the actual occurrences of igneous rocks in nature. Petrology is dependent upon, knit together with, field geology; the heart of geological philosophy is petrology in its broad sense. On the chemical side the laboratory observations of rock-analysts have been rated as "superior" (excellent, fair, or good) or as "inferior" (poor or bad). Similarly, field observations can be rated as superior or inferior according to the fulness and accuracy with which they supply the data from outdoor nature. Of those facts none is of more importance to petrology than the mode of occurrence of igneous rocks.

The field information required for the great group of the igneous intrusives relates to their shapes, sizes, and methods of intrusion. The statement of field facts depends on the precision of the terms

[1] Published by permission of the Canadian Commissioner, International Boundary Surveys.

used to describe them. That precision depends on definition. Scientific definition necessarily means classification.

Neither in the definition nor in the classification of igneous intrusive bodies is there at present unanimity or consistency among geologists. The same author defines "dike" or "sheet" or "batholith" in quite different ways on different pages. Of late years "laccolith," "boss," "stock," and practically every other term referring to igneous intrusions, have from different writers respectively received definitions varying in essentials. In several cases the difference of usage has sprung from the subjective influence of theories of intrusion. Some of the most recent definitions of older terms have thus become too intensive in meaning to fill the needs of the great body of field workers who are still in the wholesome attitude of mind that forbids the final adoption of any theory of intrusion for many important igneous bodies.

The writer believes that a comparatively full classification of igneous intrusive bodies is needed. The general adoption of a consistent, well-defined scheme of types—a scheme as complete as possible, but elastic enough to permit of new types—would tend to make field descriptions more scientific than many of them are at present. Such general adoption would mean a gain in precision, the soul of scientific writing; a gain in the ease with which a paper descriptive of igneous intrusions would be understood; and an economy of words induced by the employment of terms of definite, precise meaning. The filling-out of the scheme of classification to an extent quite beyond that now prevailing in standard text-books of geology should further have the effect of sharpening the eyes of the field observer. He may perhaps not be content to describe a given granite intrusion as simply a "mass," or an "area," or an "outcrop," if it be possible by the study of its contents to indicate the real form and relations of the granite body. The use of the term "mass" in that sense is often excellent because of the apparent impossibility of determining the true shape of the granite body; but such justifiable employment of the term implies that that particular body cannot as yet be thoroughly classified. A rather negative name has in such a case a distinct value. Of yet greater value is the positive reference of intrusive bodies to definite categories. A

good observer always feels the pressure of the category. If his classification be systematic, his observing power is quickened, his report enriched; if his classification be that in general use, his descriptions will be of the greater service to the science.

The purpose of this paper is to present certain of the current definitions and classifications of intrusive bodies; from the definitions and classifications to attempt the deduction of the various principles underlying them; and, finally, to offer for discussion a classification which shall aim at a systematic and consistent use of the principles which seem best adapted to the case. As far as possible, these principles are the same as those already in common use among leading geologists.

FORMER CLASSIFICATIONS

A few representative classifications of igneous intrusive bodies will serve to show the range of types recognized by recent authors.

I. Sir Archibald Geikie, *Text-book of Geology* (4th ed., 1903), Vol. II, p. 722:
   1. Bosses (stocks).
   2. Sills, intrusive sheets.
      Variety: laccolith.
   3. Veins and dykes.
      Varieties: contemporaneous veins, segregation veins, multiple dykes, compound dykes.
   4. Necks.

II. T. C. Chamberlin and R. D. Salisbury, *Geology* (1904), Vol. I., pp. 476, 477:
   1. Dikes.
   2. Necks or plugs.
   3. Sills.
   4. Laccoliths.
   5. Bysmaliths.
   6. Bathyliths.

III. F. Zirkel, *Lehrbuch der Petrographie* (1893), Vol. I, p. 539:
   1. Gänge.
   2. Lagergänge.
   3. Gangstöcke.
   4. Apophysen.
   5. Stöcke.
   6. Intrusivlager.
   7. Lakkolithen.

DEFINITION OF TERMS DESCRIPTIVE OF INTRUSIVE BODIES

Dike.—The best established of all the terms used in the foregoing lists is "dike;" yet the variation in even recent definitions of it is apparent in such examples as the following:

I. G. K. Gilbert:[1]

Dikes differ from sheets in that they intersect the sedimentary strata at greater or less angles, occupying fissures produced by the rupture of the strata.

II. G. P. Merrill:[2]

A dike: "an eruptive mass of varying width included between well-defined walls, and occupying a fissure or fault in previously consolidated rocks. Such are inclined at all angles with the horizon, and are usually of very moderate width, but may extend for miles."

III. T. A. Jaggar:[3]

A dike is an elongate intrusive igneous body occupying a fissure in any sort of rock, the walls of which at the time of intrusion were vertical or, if inclined, at angles nearer the vertical than the horizontal. A dike must have longitudinal extension much greater than its breadth, but may vary in thickness from an inch to several hundred feet. A dike may be irregular or may follow a sinuous course; it may be intruded between the beds of vertical or steeply inclined sediments; it frequently follows joint surfaces and has smooth and plane bounding walls. It must be noted that a flat igneous mass intruded between horizontal or nearly horizontal strata, and subsequently upturned with them to a vertical position, is not a dike, but a sill.

IV. Sir Archibald Geikie:[4]

Dykes are veins of eruptive rock, filling vertical or highly inclined fissures, and are so named on account of their resemblance to walls (Scotice, dykes).

V. T. C. Chamberlin and R. D. Salisbury:[5]

When lava is forced into crevices or rises to the surface through fissures, and the residual portion solidifies in them, it gives rise to dikes.

All the foregoing definitions agree in ascribing to a dike the characteristic form of a fissure-filling. Gilbert, in the quotation; Geikie, and Chamberlin and Salisbury, in their respective contexts, expressly exclude from the category of dikes all sheetlike intrusions thrust

[1] *Geology of the Henry Mountains* (1877), p. 20.

[2] *Rocks, Rock Weathering and Soils* (1897), p. 50.

[3] *Twenty-first Annual Report of the U. S. Geological Survey*, Part 3 (1901), p. 172.

[4] *Text-book of Geology* (4th ed., 1903), Vol. II, p. 743.

[5] *Geology* (1904), Vol. I, p. 476.

into the bedding-planes of stratified formations, whatever is or has been the angle of dip. The same usage appears in the writings of most field geologists, whether English-speaking or not. Geikie emphasizes the generality (necessity?) of high angles of dip in true dikes. Jaggar makes the angle of dip at the time of intrusion the principal criterion in distinguishing dikes from siils, and advocates a definition of both dike and sill which is not followed by the great majority of geologists. J. D. Dana[1] states that dikes may vary "in position from vertical to horizontal," and it is seen that Gilbert's and Merrill's definitions agree with that usage of the term. Since most dikes are nearly or quite vertical, the difficulty of classifying those eruptive fissure-fillings which lie nearer horizontal than vertical planes has not often been mentioned in geological literature.

Most geologists are thus agreed that dikes in stratified formations are bodies always cross-cutting the bedding planes. Many geologists agree that the angle of dip is immaterial. All agree as to the criterion of form, namely, that of a fissure-filling narrow in proportion to its length and bounded by parallel or nearly parallel walls of country rock.

According to the commonest and best usage, an igneous dike (*a*) is an injected body, (*b*) has nearly or quite parallel walls, (*c*) is narrow in proportion to its outcropping edge, (*d*) cuts across the bedding when the invaded formation is stratified, and (*e*) has any angle of dip.

When stratification and cleavage or schistosity are not coincident, such an intrusive body is generally called a dike, even though it follows the planes of cleavage or schistosity. This usage will be adopted in the classification proposed in this paper.

Multiple dikes are compound intrusions of dike form, due to successive injections of homogeneous material on the same fissure.[2] For illustrations, see Harker, *Tertiary Igneous Rocks of Skye*, pp. 296–304; A. Geikie, *Ancient Volcanoes*, Vol. II, p. 417.

Composite dikes are compound intrusions of dike form, due to successive injections of different materials into the same fissure.[3]

[1] *Manual of Geology*, 4th ed., 1895, p. 298.

[2] Geikie, *Text-book of Geology*, Vol. II, p. 746.

[3] J. W. Judd, *Quarterly Journal of the Geological Society*, London, Vol. XLIX (1893), p. 536; A. Harker, *Tertiary Igneous Rocks of Skye* ("Memoirs of the Geological Survey of Great Britain," 1904), p. 197.

A. Geikie has used "compound" in the sense of "composite" in the foregoing definition;[1] Lawson has used "multiple" with the same meaning. The nomenclature given in the above definitions is preferred, as it brings out the analogy with "multiple" and "composite" sills and laccoliths—types already well named and established.

A composite dike is illustrated in Fig. 1.

A *dike network* is a reticulate group of dikes simultaneously

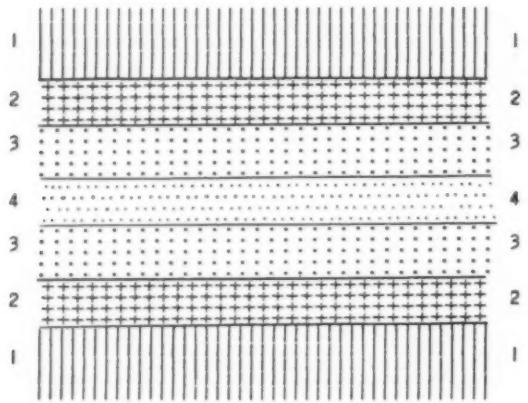


FIG. 1

injected. For illustration see *Bulletin No. 209*, U. S. Geological Survey, 1903, section, Plate 7.

Intrusive vein.

I. J. B. Jukes:[2]

When the injected mass has arisen along an opened fissure, and solidified there as a wall-like intrusion, it is called a *dyke*. When its path has been less regularly defined, and penetrates the surrounding rocks in a wavy thread-like fashion, this irregular protrusion is called a *vein*.

II. A. Geikie:[3]

Veins have been injected into irregular branching cracks.

[1] *Text-book*, Vol. II, p. 746.

[2] *Manual of Geology*, edited by A. Geikie (1872), p. 263.

[3] *Text-book* (1903), p. 744.

Contemporaneous vein.

Forms part of the igneous rock in which it occurs, but belongs to a later period of consolidation than the portion into which it has been injected.[1]

Apophyses or tongues are dikes or veins which, either directly or by inference from field relations, can be traced to larger intrusive bodies as the source of magmatic supply for dike or vein.[2]

Intrusive sheet.—This familiar expression has generally been defined as equivalent in meaning to "sill."[3] It may well be extended to cover the case of an igneous layer injected on a plane of unconformity in stratified formations, when the igneous layer is thus sensibly parallel to the bedding-planes of one of the stratified formations. This type, for lack of a better term, may be called an *interformational sheet.* For illustration of such a sheet on a colossal scale, see "Map of Northern Nickel Range," Sudbury District, Ontario, by A. P. Coleman.[4]

Sill.

I. A. Geikie:[5]

A *sill* is a sheet of igneous material which has been injected into a sedimentary series and has solidified there, so as to appear more or less regularly intercalated between the strata.[6]

II. T. A. Jaggar.[7]

A sill is an intrusive sheet forced between strata which are horizontal or which, if tilted, lie at angles more nearly horizontal than vertical. . . . . Transitions between dike and sill occur when a sill breaks upward at an angle of 45°, or when a dike follows the bedding-planes of strata inclined at that angle.

III. Chamberlin and Salisbury:[8]

If the lava is forced between beds of rock in the form of a sheet, and solidifies there, it is called a *sill.*

The definition of I and III is that which is adopted by nearly all

[1] Geikie, *op. cit.*, p. 738.

[2] See A. Geikie, *Quarterly Journal of the Geological Society*, Vol. L (1894), p. 222, and *Ancient Volcanoes of Great Britain*, Vol. II (1897), p. 439.

[3] E. g., Jukes, *Manual*, p. 254; Gilbert, *op. cit.*, p. 20; Iddings, *Twelfth Annual Report of the U. S. Geological Survey*, Part 1, p. 578; Geikie, *Text-book*, p. 732.

[4] *Report of the Bureau of Mines*, Ontario, 1904.

[5] *Geology of Eastern Fife* ("Memoirs of the Geological Survey of Scotland," 1902), p. 189.

[6] Cf Geikie, *Text-book*, p. 732. [7] *Op. cit.*, p. 172. [8] *Op. cit.*, p. 476.

authors writing in English on this type of intrusive body. The term "sill" has also its equivalents in this sense in other languages. Definition II is not only contrary to general usage but suffers from special imperfections due to the artificial nature of the chief criterion distinguishing dike and sill. (Compare Definition III of "dike.") Among those imperfections is the difficulty of classifying by Definition II many intercalated sheets now dipping at high angles, for with them it may be impossible to say what were their original dips.

It thus seems best to adhere to the prevailing use of the term "sill" in a systematic classification of intrusive bodies. A sill may be of

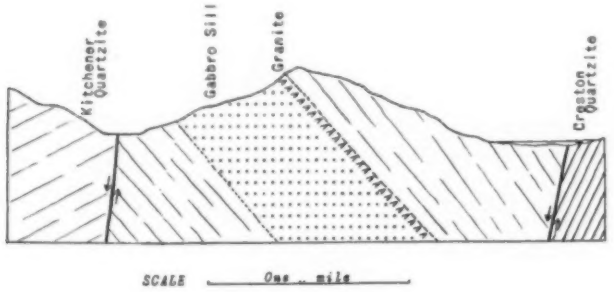


FIG. 2

great thickness, as illustrated on Fig. 2, but it is necessary that the sheet shall hold its thickness for considerable distances along its outcropping edge.

A *multiple sill* is a compound intrusion of sill form and relations, and is the result of successive injections of one kind of magma along a bedding-plane in a stratified formation.[1] For a remarkable illustration, see Harker.[2]

A *composite sill* is a compound intrusion of sill form and relations, and is the result of successive injections of more than one kind of magma along a bedding-plane in a stratified formation.[3]

A section of a composite sill is illustrated in Fig. 3.

[1] See A. Geikie, *Ancient Volcanoes of Great Britain*, Vol. II, pp. 318 ff.; and especially A. Harker, *op. cit.*, p. 197.

[2] *Op. cit.*, p. 239.

[3] See Harker and Geikie, same pages as noted for multiple sills.

Laccolith.—Divergence of definition and usage becomes very marked in the case of the term "laccolith."

I. The original definition by G. K. Gilbert:

The station of the laccolite being decided, the first step in its formation is the intrusion along a parting of strata, of a thin sheet of lava, which spreads until it has an area adequate, on the principle of the hydrostatic press, to the deformation of the covering strata. The spreading sheet always extends itself in the direction of least resistance, and, if the resistances are equal on all sides, takes a circular form. So soon as the lava can uparch the strata, it does so, and the sheet becomes a laccolite. With the continued addition of lava, the laccolite grows in height and width, until finally the supply of material or the propelling force so far diminishes that the lava clogs by congelation in its conduit and the inflow stops.[1]

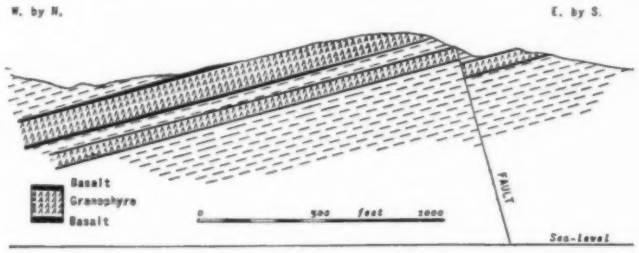


FIG. 3

As a rule, laccolites are compact in form. The base, which in eleven localities was seen in section, was found flat, except where it copied the curvature of some inferior arch. Wherever the ground plan could be observed, it was found to be a short oval, the ratio of the two diameters not exceeding that of three to two. Where the profile could be observed, it was usually found to be a simple curve, convex upward, but in a few cases, and especially in that of the Marvine laccolite, the upper surface undulates. The height is never more than one-third of the width, but is frequently much less, and the average ratio of all the measurements I am able to combine is one to seven.

The ground plan approximates a circle, and the type form is probably a solid of revolution—such as the half of an oblate spheroid.[2]

The laccolite is a greatly thickened sheet [sill] and the sheet [sill] is a broad, thin, attenuated laccolite.[3]

The laccolite in its formation is constantly solving a problem of "least force," and its form is a result. . . . . A laccolite grows "by lifting its cover."[4]

The clearness and precision of Gilbert's description gives a distinct and unmistakable individuality to his original type. It is a

[1] *Op. cit.* (1877), p. 95. [2] *Ibid.*, p. 55. [3] *Ibid.*, p. 20. [4] *Ibid.*, p. 91.

greatly thickened sill of compact, domical form, with (*a*) a limital thickness, (*b*) a limital area, (*c*) a flat base, (*d*) an oval or circular ground plan, and (*e*) a specialized method of intrusion, namely, by lifting a stratified cover which thus assumes a dome structure.

Gilbert notes, as a first variation on the simple type, a compound type of laccolith which is "built up of distinct layers. . . . . It is probable that all the larger laccolites are composite, having been built up by the accession of a number of distinct intrusions."[1]

He continues:

> If the strata had experienced anterior displacements so as to be inclined, folded, and faulted, a symmetrical growth of laccolites would have been impossible, and the mountains would not have yielded a knowledge of the type form. But the type form being known, it is to be anticipated that in disturbed regions aberrant forms will be recognized and referred to the type.[2]

II. Cross[3] illustrates many examples of true laccoliths which show aberrant forms in just such a way as was foretold by Gilbert. Cross still holds that the body is a laccolith even if its expansion has taken place from a plane only approximately parallel to the bedding of the invaded strata. He emphasizes the asymmetric dome as more nearly the real shape of a laccolith in nature, and attributes such irregularity of form chiefly to lines of weakness existing in the sedimentary formation before intrusion took place. A more fundamental difference between the definitions of Gilbert and Cross appears in their respective statements as to the method of intrusion. Cross holds that the deformation of the stratified cover is in many cases not simply due to the force of a gigantic hydrostatic press; that the deformation was then incidental to the gaping of strata undergoing lateral, orogenic pressure, the magma being more or less passive as it was injected.

III. Weed and Pirsson[4] agree with the views of Cross, but Pirsson returns to the idea of the hydrostatic press as explanatory of the intrusions in the Judith Mountains. Both authors consider that a horizontal base is not necessary for a true laccolith, and that some laccoliths are doubly convex.

[1] *Op. cit.*, p. 55. [2] *Ibid.*, p. 98.

[3] *Fourteenth Annual Report*, U. S. Geological Survey, Part 2 (1894), pp. 184 ff.

[4] *Eighteenth Annual Report*, U. S. Geological Survey, Part 3 (1898), p. 581.

IV. Jaggar[1] found that the laccoliths of the Black Hills illustrated conclusions essentially equivalent to those of Cross, states his belief that the magmas were mostly passive during intrusion, the laccolith chambers being opened by orogenic stresses, and remarks that laccoliths may be doubly convex.

V. The recent definition of Chamberlin and Salisbury[2] returns once more to the original type of Gilbert: "If, after rising to a certain point in the strata, the lava arches the beds above into a dome, and forms a great lens-like or cistern-like mass, it constitutes a *laccolith*."

It is seen that there is considerable diversity of usage for the term "laccolith." On the whole, this diversity is a sign of progress in geological science. Gilbert's ideal type has been supplemented by others that vary from the ideal in one or more particulars, under conditions which Gilbert himself foretold, if it were but in brief expression.

Those who have made actual researches among laccoliths, and have preserved the term "laccolith" with the original meaning of Gilbert's broader definition, are agreed on the following characteristics: (*a*) Whatever the origin of the force involved, a laccolith is always *injected*. (*b*) A laccolith is always in sill-relation to the invaded, stratified, formation; that is, the injection has, in the main, followed a bedding-plane; but, like sills, laccoliths often locally break across the bedding. (*c*) A laccolith has the shape of a plano-convex or doubly-convex lens flattened in the plane of bedding of the invaded formation. The lens may be symmetric or asymmetric in profile, circular, oval, or irregular in ground plan. (*d*) There are all transitions between sills and laccoliths.

For many illustrations of simple symmetric and asymmetric laccoliths, see the cited writings of Gilbert, Cross, Weed and Pirsson, and Jaggar.

Compound laccolith.—In the Judith Mountain type, as in the larger examples of laccoliths in the Henry Mountains, the whole intrusive body is divided by strong beds of the invaded formation. This gives the appearance of a number of distinct intrusions, one of them dominating, the others subsidiary, in size, but all of them composed of the

[1] *Op. cit.*, p. 173. [2] *Geology*, Vol. I, p. 476.

same kind of material. If the magma has all been intruded at practically the same time, we have the "compound laccolith" of Weed and Pirsson.[1]

A *multiple laccolith* may be conceived, the name being formed on the analogy of "multiple dike" and "multiple sill." It would differ from a compound laccolith only in the fact that the deformation of the strata, while again similar in character to that produced during the intrusion of a simple laccolith, has been due to distinctly successive injections of the same kind of magma. This case has not yet been described as actually occurring in nature.

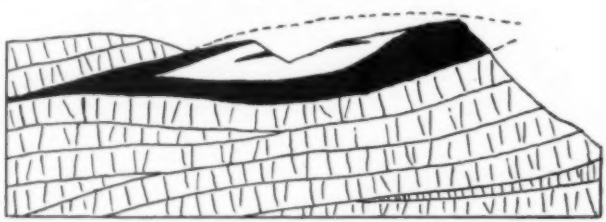


FIG. 4

Composite laccolith.—Harker[2] has noted the occurrence of "composite laccoliths" in the island of Skye. The analogy with composite dike and sill is again perfect. The principal distinction from both compound and multiple laccoliths is found in the heterogeneous nature of the magma successively injected in this last case. (See Fig. 4.)

Interformational laccolith.—Weed and Pirsson[3] have described as a laccolith a great, lenticular mass of porphyry injected along a surface of unconformity, namely, that between pre-Cambrian crystalline schists and a sedimentary Cambrian formation. Such a type is again aberrant from Gilbert's types, but should certainly be classed among the laccoliths; the writer proposes the not altogether satisfactory name "interformational laccolith" for this case. (See Fig. 5, and compare a similar section of an occurrence in the Black Hills of South Dakota, published in the *Annals of the New York Academy of Sciences*, Vol. XII (1899), p. 212.)

[1] *Op. cit.*, p. 580; see figure.

[2] *Op. cit.*, p. 209.

[3] *Journal of Geology*, Vol. IV (1896), p. 402.

Plug.—Russell has described as "plutonic plugs" certain intrusions occurring in the Black Hills of Dakota. They "are composed of igneous matter forced into sedimentary strata and have a plug-like form."[1] He continues: "How the stratified beds below the domes that covered the plugs were displaced, or perhaps fused, so as to furnish room for the passage of the intruded material, is not clear." Again: "None of the plutonic plugs examined by me are associated with dikes or faults."[2] "They occur in a region where the stratified rock into which they were forced are essentially horizontal."[3]

Since neither the form nor the method of intrusion is clearly indicated, it is difficult to classify "plugs" in Russell's sense. It is

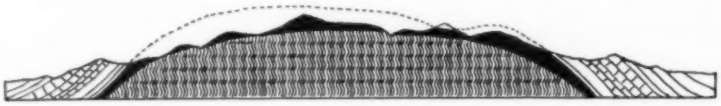


FIG. 5

to be noted that Jaggar[4] and Iddings[5] interpret some of Russell's original types as true laccoliths. Russell's statement does not make clear the distinction between "plugs" and stocks. The name "plug" has been rather commonly used as alternative with the magmatic filling of a volcanic vent.[6] For these various reasons, "plugs" will not be included in the proposed classification of this paper.

Bysmaliths.—Allied to "plugs" in Russell's sense is the "bysmalith" of Iddings, described as an injected body filling a "more or less circular cone or cylinder of strata, having the form of a plug, which might be driven out at the surface of the earth, or might terminate in a dome of strata resembling the dome over a laccolith."[7] The downward termination of the original type bysmalith (Mt. Holmes) is found in a hypothetical Archean floor on which the porphyry of the bysmalith rests. See illustrations.[8]

[1] *Journal of Geology*, Vol. IV (1896), p. 25.

[2] *Ibid.*, p. 42.

[3] *Ibid.*, p. 183.

[4] *Op. cit.*, p. 287.

[5] *Journal of Geology*, Vol. VI (1898), p. 706.

[6] Recently by Merrill, *op. cit.*, p. 51, and by Chamberlin and Salisbury, *op. cit.*, p. 476.

[7] *Monograph No. 32*, Part 2, U. S. Geological Survey (1899), p. 16.

[8] Iddings, *op. cit.*, p. 16; and *Journal of Geology*, Vol. VI (1898), p. 708.

Volcanic neck.—The solid-lava filling of a volcanic vent is evidently intrusive with reference to the formations traversed by the lava, whether those formations are composed of non-volcanic rocks or of agglomerate or tuff which has been pierced by thoroughly molten lava on its way to the surface. (See Fig. 6.)

"*Chonolith.*"—There remains for distinction a class of injected igneous bodies which are not included in any of the above-mentioned categories. In the dislocation of rock formations such as is brought about during mountain-building, actual or potential cavities are formed within the earth's crust. These are commonly filled with igneous magma squeezed into the individual cavity from below, from

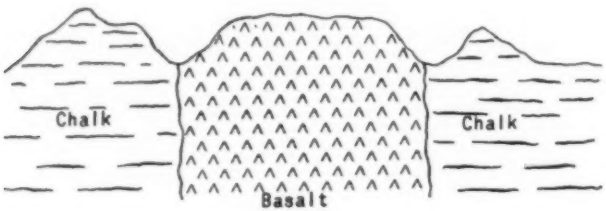


FIG. 6

the side, or, it may be, from above. Dikes, sills, and bodies of laccolithic form (though not strictly of the laccolithic mode of intrusion, as designated by Gilbert) may thus originate. Yet very often the shape of the intruded mass is so irregular, and its relations to the invaded formations so complicated, that the body cannot be classified in any of the divisions so far named. Again, irregular injected bodies of a similarly indefinite variety or form are due to the active crowding-aside and mashing of the country-rock which is forced asunder by the magma under pressure. Or, thirdly, such bodies may be due to a combination of the two primary causes—orogenic stress opening cavities, and hydrostatic or other pressure emanating from the magma itself and widening the cavities.

The number and total volume of these irregular intrusions doubtless greatly exceed the number and volume of all the true laccoliths of the world. In the average mountain range the geologist is more likely to encounter injected bodies of the former kind than he is to discover true laccoliths.

No generally accepted name has yet been proposed for such irregular intrusions. "Laccolith" cannot be used, since that term denotes a definite form, and also implies a special mode of intrusion different from that here conceived. The writer has not been able to find a simple English word for the purpose, and suggests a name formed from the Greek on the analogy of "laccolith," "bysmalith," and "batholith." It is "chonolith," derived from χῶνος, a mold used in the casting of metal, and λίθος a stone. The magma of a "chonolith" fills its chamber after the manner of a metal casting filling the mold. Like a casting, the "chonolith" may have any shape.

A "chonolith" may be thus defined: "an igneous body (*a*) *in*jected into dislocated rock of any kind, stratified or not;[1] (*b*) of shape and relations irregular in the sense that they are not those of a true dike, vein, sheet, laccolith, bysmalith, or neck; and (*c*) composed of magma either passively squeezed into a subterranean orogenic chamber or actively forcing apart the country-rocks.

The chamber of a "chonolith" may be enlarged to a subordinate degree by contact fusion on the walls, or by magmatic "stoping."

An example of a "chonolith" is illustrated in Fig. 7.

Many intrusive bodies that have been mapped and illustrated with sections seem to belong to this same category. Among these may be mentioned a few taken from works dealing with the western Cordillera of the United States.

In the Little Belt Mountains folio of the U. S. Geological Survey, several "stocks" of granite, diorite, etc., are sectioned with relatively narrow feeding channels from below. The Three Forks (Montana) folio contains a map and section of a "laccolith" in non-laccolithic relations. Section "M–M" of the Ten Mile District Special folio shows a mass of granite injected after the manner of a "chonolith." South of Mount Stuart, Washington, the Mount Stuart folio illustrates an irregular intrusion of peridotite with "chonolithic" relations.

Cross[2] states that the intrusive body of Mount Carbon, Colorado, is injected and irregularly cross-cutting; it is not a true laccolith, but appears to be best placed in such a class as that here proposed.

[1] The term "injected" is used here and elsewhere in this paper in a sense defined in the third paragraph of the following section on the principles of classification.

[2] *Op. cit.*, p. 191.

Weed and Pirsson[1] describe Judith Peak, Montana, as underlain by a "stock" of porphyry. Their section of the "stock" shows, however, a rapid constriction of the body as the section is followed downward. As will be noted on a following page, the section of a true stock typically enlarges downward so that such a body is "subjacent" rather than "injected" with respect to the invaded formations. On the supposition that the section of Weed and Pirsson

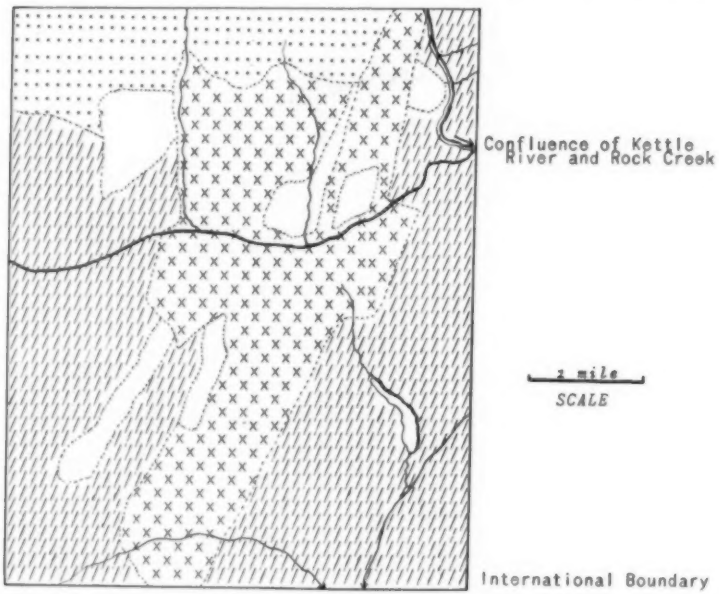


FIG. 7

correctly represents the actual underground relations, the Judith Mountain body has its nearest relatives among "chonoliths" and not among "stocks."

Jaggar[2] describes the intrusive bodies of Dome Mountain and Whitewood Canyon in the Black Hills as injected bodies of marked irregularity both in shape and in relations to their respective country-rock formations. These bodies seem to be transitional between

[1] *Eighteenth Annual Report*, U. S. Geological Survey, Part 3, 1898, p. 533.

[2] *Op. cit.*, Plates 20 and 21, and pp. 209 and 217.

true laccoliths and typical "chonoliths," but belong to the latter class rather than to the former. Jaggar also describes the "False Bottom Stock" of phonolite in such terms as to lead one to suspect that it may be another, perhaps typical, body of the "chonolith" class.[1]

Jaggar,[2] collaborating with Howe, has experimentally reproduced the conditions under which some "chonoliths" have originated; namely, such bodies as have been injected primarily through the application of force resident in fluid magma under pressure (hydrostatic force). No attempt was made, in their valuable experiments, to imitate injection concomitant with regional deformation.

Whatever may be the validity of any or all of these several cases as illustrations of "chonoliths," there is no question that they can be called "stocks" or "laccoliths," or by any other of the established names, only at the sacrifice of much of the strength, precision, and usefulness of those names. On the other hand, there are thousands of irregular injected bodies which cannot properly be described by the use of any of the established names. It is to be noted, finally, that some such term as "chonolith" may be useful in suggesting the probable nature of an intrusive body in the case where its whole form is not certainly known. The context should then, of course, indicate that the author using the term has in mind only a probability and is making, as it were, simply a report of progress in the description of that particular body.

Boss.—A Geikie[3] defines bosses as

> masses of intrusive rock which form at the surface rounded, craggy, or variously shaped eminences, having a circular, elliptical or irregular ground plan, and descending into the earth with vertical or steeply inclined sides. Sometimes they are seen to have pushed the surrounding rocks aside. In other places they seem to occupy the place of these rocks through which, as it were, an opening has been punched for the reception of the intrusive material. . . . . In true bosses, unlike sills or laccolites, we do not get to any bottom on which the eruptive material rests.

He makes "stock" and "boss" synonymous.

In his *Text-book*[4] Geikie says: "Bosses (stocks) are amorphous masses that have disrupted the rocks through which they rise."[5]

[1] *Ibid.*, p. 227.

[2] *Ibid.*, p. 302, and Plate 43, section 2.

[3] *Ancient Volcanoes*, Vol. I (1897), p. 88.

[4] Vol. II (1903), p. 722.

[5] Cf. also A. Geikie, *Geology of Eastern Fife* (1902), p. 189.

In English- and German-speaking countries "boss" and "stock" are almost invariably regarded as synonymous, but the latter term has much the greater vogue.[1] The general connotation of the word "boss" seems to warrant the restriction of its meaning so as to include only those stocks which have circular or subcircular ground plans on the surface of exposure. The word has been used to denote intrusions of the sort up to all diameters from a few hundred feet to several miles.

Bosses are "simple" when composed of material intruded in but one period; they are "multiple" or "composite" when composed of material intruded at two or more distinct periods of irruption. The distinction between the latter types is the same as between "multiple" and "composite" stocks.

An illustration of a simple boss is given in Fig. 8.

Stock.—Prevailing usage has fixed the meaning of "stock" as essentially equivalent to Geikie's definition of "boss." A stock is an intrusive body, but is not as clearly *in*jected as is the case with a dike, sill, or laccolith. A stock more or less conspicuously cuts across the structures of the invaded formations; its contacts are, in general, either vertical or highly inclined; its shape is irregular and not determined by planes of bedding or other structures in the country-rocks. It has no visible floor. Van Hise regards a stock as characteristically smaller than a boss,[2] but the present writer has found that general usage does not support that distinction.

Simple stocks are composed of material intruded in one period of irruption.

A *multiple stock* is composed of material demonstrably intruded in two or more periods of irruption, the material having been derived from the same kind of magma.

A *composite stock* is composed of materials demonstrably intruded in two or more periods of irruption, the materials having been originally derived from two or more kinds of magma. (Fig. 8.)

Magmatic differentiation or other influences may render heterogeneous the material composing a simple stock, or each member of either a multiple or a composite stock.

[1] Cf. Zirkel, *Lehrbuch der Petrographie* (1893), Vol. I, p. 539.

[2] *Monograph No. 47*, U. S. Geological Survey (1904), p. 711.

Batholith.—Suess[1] has finally stated the definition of "batholith" in terms of a theory of intrusion which is at present in discussion. His definition may be freely translated thus: "A batholith is a stock-shaped or shield-shaped mass intruded as the result of fusion of older formations (orig. *Durchschmelzungsmasse*). On the removal of its rock-cover and on continued denudation, this mass either holds its

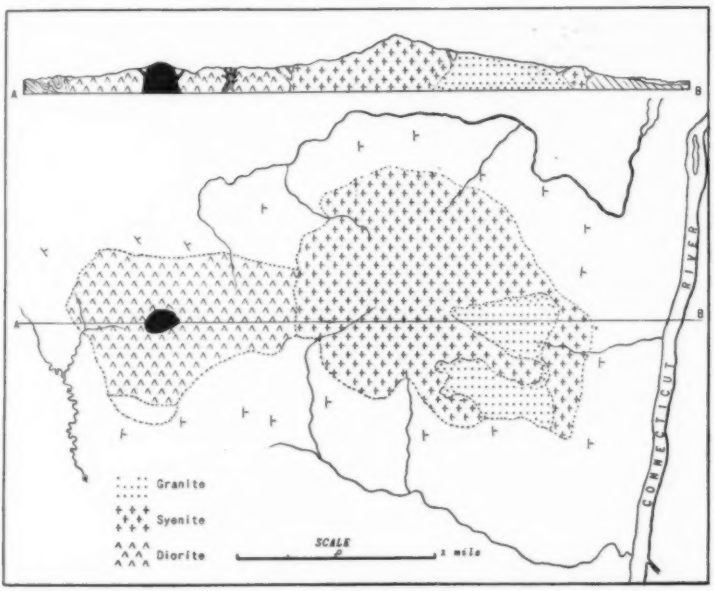


FIG. 8

diameter or grows broader to unknown depths (orig. *bis in die ewige Teufe*).[2] The name was invented to describe those largest of all intrusions, generally granitic, which are characteristically found in great mountain ranges; including, thus, "central granites," "intrusive mountain-cores," "Fussgranit," etc. The name has since been commonly used for bodies of intrusive rock with the general characteristics of stocks, but of much larger size than is generally attributed to stocks or bosses. This latter use is, moreover, rarely

[1] *Sitzungsberichte der Wiener Akademie*, Vol. CIV (1895), p. 52.

[2] Compare Chamberlin and Salisbury, *op. cit.*, p. 477; and W. Salomon, Tschermak's *Mineralogische und petrographische Mittheilungen*, Vol. XVII (1897), p. 31.

associated directly with any particular theory of intrusion. There is pressing need for such a term signifying these large bodies, and one that will not commit the field worker to any theory of origins. The later use of the term "batholith" is therefore to be commended, as it renders that term much more useful in actual field descriptions where these cannot be accompanied with certain proofs of the *Durch-*

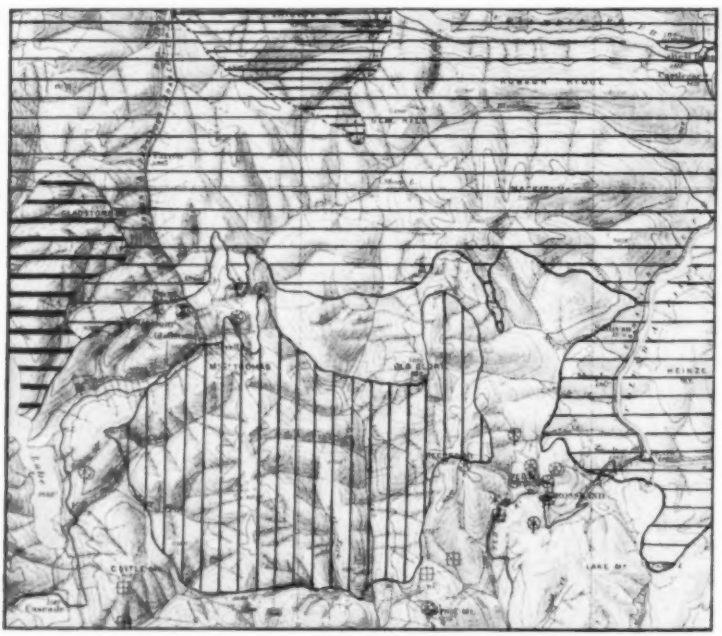


FIG. 9

schmelzung theory as there applicable. In the proposed classification of intrusives the term "batholith" will have the meaning just noted.

A *simple batholith* is one composed of material intruded in one period of intrusion. (Fig. 9).

A *multiple batholith* is one composed of material demonstrably intruded in two or more periods of irruption, the material having been derived from the same kind of magma.

A *composite batholith* is one composed of materials demonstrably

intruded in two or more periods of irruption, the materials being originally derived from two or more kinds of magma. (Fig. 9.)

A multiple or composite batholith may thus be in part made up of stocks.

Magmatic differentiation or other influences may render heterogeneous the material composing a simple batholith; or each member of a multiple or a composite batholith.

No author has attempted to fix a lower limit to the areal dimensions of a batholith. Since there is no certain distinction either in form or relations between stocks and batholiths, an arbitrary limit may be set between the two on the score of areal extent. It may be proposed that a body of the kind exposed in an area of less than 200 square kilometers is a stock; a similar body with a larger area is, accordingly, a batholith.

PRINCIPLES OF CLASSIFICATION

A review of the foregoing definitions shows that each of them has been based on one or more primary features of igneous intrusions, namely:

a) The method of intrusion.

b) The relation of the body to pre-intrusion structures in the invaded formation.

c) The form of the body.

d) The size of the body.

e) The attitude of the body with reference to the horizontal plane.

For a given body the method of intrusion is the most important criterion that could be used in classification. If it might be determined in every detail just how the igneous mass reached its present position, the form of the body and its relation to structural planes in the country-rock would therewith be known. A genetic, and therefore natural, classification should thus be founded on the method of intrusion. In the present state of geological science it is, however, impossible to apply this fundamental principle throughout the established list of intrusive bodies.

The greater number of recognized types are those of bodies of magma which is exotic except for a small, variable portion of it due to contact fusion. In each of these cases the magma has come into

its chamber through channels which have fed the growing body from larger, deeper-lying, generally invisible reservoirs. The chamber is due to a parting of the country-rock into which the magma is *in*jected. An injected body is thus one which is entirely inclosed within the invaded formations, except along the relatively narrow openings to the chamber where the latter has been in communication with the feeding reservoir.

On the other hand, stocks, bosses, and batholiths never show a true floor. They appear to communicate directly with their respective magma reservoirs. Each of these bodies shows field relations suggesting that it is a *part* of its magma reservoir. The communication with the magmatic interior of the earth is not established by narrow openings, but by a huge, downwardly enlarging opening through the country-rock. In relation to the invaded formations a stock, boss, or batholith is intrusive, but is *subjacent* rather than injected.

How a magma reservoir is enlarged by the volume represented in the amount of intrusion signalized on the contacts of stock or batholith is a matter permitting as yet of no absolute certainty. In separating intrusive bodies into two primary divisions, one including all injected bodies, the other including subjacent bodies, a classification will do good service in emphasizing the need of further investigation into the mechanics of intrusion. No one has yet proved that any granite mass over 200 square kilometers in area, and characterized by vertical or outwardly sloping contact surfaces, is due to injection. Whatever may be the probabilities, no one has yet proved that such a mass has been intruded by any kind of assimilation of the invaded formations. Some light has been shed on the origin of batholiths and stocks, but they are certainly not understood as are dikes and sills.

So far as the method of intrusion is concerned, therefore, stocks, bosses, and batholiths belong to a primary division of intrusive bodies which may be defined as not demonstrably due to injection. The principle is negative; it leaves the method of intrusion unstated, but it brings into clear relief a principal contrast subsisting between the greatest of intrusions, on the one hand, and dikes, sheets, laccoliths, etc., on the other.

The other principles of classification—viz., *b*), *c*), *d*), and *e*)—are applied in the classification now to be presented in a manner sufficiently obvious to need no discussion. Principle *e*) is less fundamental than the others, excepting *d*,) and is recognized as appearing only occasionally in the scheme: the major diameters of true laccoliths tend to horizontality; a principal axis of a bysmalith, neck, stock, boss, or batholith is characteristically vertical.

It is obvious that transitional forms are to be expected among the related types of the classification. These forms have not been mentioned in the table, which would thus have become overburdened. Magmatic differentiation within the chambers of dikes, sills, stocks, etc., has often produced varietal types of these bodies, but the process has occurred too irregularly to permit of its furnishing a convenient criterion for the general classification.

PROPOSED CLASSIFICATION OF IGNEOUS INTRUSIVE BODIES

A. *Masses due to injection of exotic material.*

I. *Injection along planes of stratification in invaded formation.*

1. Intrusive sheets.
   - *a*) Sills.
     - (1) Simple.
     - (2) Multiple.
     - (3) Composite.
   - *b*) Interformational sheets.
2. Laccoliths.
   - (1) Simple.
     - Symmetric.
     - Asymmetric.
   - (2) Compound.
   - (3) Multiple.
   - (4) Composite.
   - (5) Interformational.

II. *Injection across planes of stratification in invaded formation.*

1. Dikes.
   - (1) Simple.
     - Dike-networks.
   - (2) Multiple.
   - (3) Composite.
2. Eruptive veins.

Contemporaneous veins.

3. Apophyses or tongues.

4. Bysmaliths.
5. Necks.
6. "Chonoliths."

B. *Masses due to processes other than injection; subjacent bodies.*

1. Stocks and bosses.
   (1) Simple.
   (2) Multiple.
   (3) Composite.
2. Batholiths.
   (1) Simple.
   (2) Multiple.
   (3) Composite.

GLAUCONITE

J. K. PRATHER
Waco, Tex.

The samples of glauconite were taken from the (Cretaceous) Greensands of New Jersey.[1]

William B. Clark states that there are "two conditions necessary in the development of glauconite (1) deposition of particles of land derived origin, and (2) the presence of Foraminifera."

Murray and Renard state:

> The chambers become filled with muddy sediment, and if we admit that the organic matter inclosed in the shell and in the mud itself transforms the iron into sulphide, which may be oxidized into hydrate, sulphur being at the same time liberated, this sulphur would become oxidized into sulphuric acid, which would decompose the fine clay, setting free colloid silica and hydrated oxide of iron in a state most suitable for their combination.

Leith says:

> It is difficult to see how so high a percentage of iron as is found either in glauconite or greenalite can be derived from the decomposition of mud filtered into the interior of the shell. The contents of metallic iron shown in the analysis of the greenalite rock is 25 per cent. In the typical glauconite deposits foreign material is present outside of the shells, and there seems to be no reason why all this material should not be drawn upon for the supply of iron.[2]

He further states:

> Where iron is being contributed to ocean waters in considerable abundance, it is possible to conceive of minute organisms abstracting the same and depositing it directly in such form as glauconite or greenalite.

The New Jersey glauconite was deposited in comparatively shallow water, as is shown by the land-derived material present even in the purest samples of glauconite, and the cross-bedding.

In the glauconite I have studied, the casts of shells of Foraminifera seem to be the exception rather than the rule. The grains are

[1] See The Atlantic Highlands Section of the New Jersey Cretacic, *American Geologist*, 1905.

[2] *Monograph 43* of the U. S. Geological Survey: "The Mesabi Iron-Bearing District of Minnesota," pp. 254.

rounded, but, except for one instance, there seems to be no indication that a shell once surrounded them. In one sample the perfect shells of Foraminifera were found among the glauconite grains, which would seem to oppose the idea that the glauconite was first contained in the shells, which were afterward dissolved by the action of sea water.

While glauconite does not have the concentric lines generally seen in the oölites, yet the similarity in shape and structure to grains of oölite, which do not show the concentric lines, suggests that many of the rounded grains of glauconite are concretions, and formed in a manner similar to that of the oölites. In some grains of glauconite was noted an indication toward concentric lines. The silica, lime, and iron which form the oölites tend to take the concentric structure more readily than does the glauconite.

The New Jersey beds contain glauconite in pockets, masses of glauconite, grains with some cementing clay, or as disseminated grains of glauconite. Where there is much clay present, the conditions are not so favorable for the further concentration of the glauconite as when it is more arenaceous.

The Navesink, a greensand bed from which most of my samples were taken, is composed of grains of glauconite with more or less clay and fragments of the older rocks. It also contains a clay iron stone, concretionary in form, which contains grains of glauconite.

The Redbank sand overlying the Navesink is composed of quartz grains, and contains glauconite which is easily affected by water and oxidizes, and gives the red and yellow colors so prominent in this bed. I have picked out round grains of magnetite with a weak bar magnet from this material which may have been originally grains of glauconite. Limonite is seen filling cracks in the clay bed at the top of the Navesink underneath and replacing fossils.

Pieces of limonite the size of a hand were collected from the Redbank. The slides in which the grains show the greatest alteration are from samples from the Redbank.

Van Hise[1] shows that hematite, limonite, magnetite, greenerite, pyrite, etc., change from one form to the other, so that glauconite altering to one form may be changed into any of the others.

[1] *Monograph 47* of the U. S. Geological Survey, on "Metamorphism."

By putting some glauconite in a test-tube and heating with conc. HNO_3, and afterward diluting and adding NH_4OH (conc.), an iron test is obtained.

The slides show glauconite grains little altered, in the midst of which is a grain greatly altered. In other slides a few grains are unaltered, while most of the grains are highly altered, indicating two kinds of glauconite, probably deposited at different times. The size of the grains also varies greatly.

Some slides show glauconite altering to limonite; others, glauconite to clay; others, glauconite to hematite; others, glauconite to magnetite; and others, glauconite to hornblende or mica. Glauconite, both solid and fibrous, is found coating grains of quartz, feldspar, mica, pyroxene, etc.

The slides show also clay, quartz, orthoclase, microclene, rutile, and mica. Some slides are almost all clay, with a few grains of glauconite, while others are made up almost entirely of glauconite grains, with the decomposition products filling in the spaces between the grains, and extending from the margins inward toward the center of the grains.

In a slide from a clay ironstone bed in the Navesink are rounded grains of glauconite, grains partly fibrous, rectangular, and broad and irregular oval, so that there is a considerable variation both in the size and in the shape of the glauconite grains.

There is a fibrous kind of glauconite which may, in some instances, be due to the alteration to hornblende, mica, or some allied mineral. In some glauconite grains are rows of small grains of magnetite. All gradations are noted from unaltered glauconite, to glauconite changed to a network of magnetite. In a slide are quartz grains and quartz containing magnetite. Magnetite is seen filling the cracks in glauconite.

In a slide there is a shell of a Foraminifera cut through, which shows the division walls of the shell. The chambers in this shell are filled with what might be called ocean mud filtered in, rather than glauconite, as it differs from the glauconite seen in the same slide both in color and behavior under the crossed nicols, indicating a slightly different mineral composition, as if it (having been inclosed in the shell, and thereby separated from the surrounding material)

lacked some of the chemical components which go to make up the glauconite. The slides were prepared by boiling in Canada balsam to render them hard before grinding down.

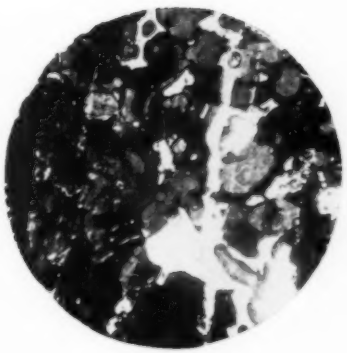
In a sample examined from Bed 2, *Gypheæ vesicularis* bed, of the Navesink, the purest sample of glauconite I had, there were five specimens of Foraminifera (Nautiloid type, Trochoid type, Nucularia type, and Nodosaria type), but the shells were still intact, and the shape and size differed considerably from the glauconite grains.

Some glauconite grains are solid, while others have fine lines running across them, as if they had been further divided up. Some grains would seem to indicate by their shape that they had been formed inside a shell, but other evidence of this seems to be lacking.

TABULAR LIST OF SLIDES

Bed[1]	Slide	
Nav.....	Ca	Two altered grains of glauconite surrounded by fresh grains
Nav.....	E_4	Same as above, but with more alteration
Nav.....	Ca	Glauconite altered to magnetite
Mat.....	p	Contains glauconite, muscovite, microcline, quartz, rutile in quartz, glauconite altered to iron
Mat.....	E_5	Same as preceding
Mat.....	typ.	Same as two preceding, but smaller mineral particles
Nav.....	gyp.	Fibrous glauconite, gypsum surrounded by glauconite, and inclosing grains of quartz and glauconite.
Nav.....	B_1	Altered and unaltered grains and a clay ground-mass
Nav.....	G_3	Much clay, alteration to clay, and also to magnetite
Nav.....	G_2	Glauconite unaltered, and partly altered to magnetite.
Nav.....	G_1	Abundance of quartz and feldspar, and little glauconite
Nav.....	A_1	Alteration chiefly to hematite
Nav.....	24	Grains of microcline and mica coated by glauconite, which is also partly altered to magnetite, masses of pyrite (secondary), fibrous glauconite
Nav.....	8	Glauconite coating mica, rounded, oval, semicircular, and rectangular grains of glauconite, and a cross-section of a Foraminifera mentioned above, grains of quartz, orthoclase, microclene, pyroxene, mica, plagioclase, a quartz grain coated by glauconite which is partly altered to magnetite
Nav.....	22	A large grain of glauconite made up of aggregates which readily separate; also contains mica, quartz, gypsum, glauconite, etc.
Nav.....	25	Microclene coated by glauconite and shattered grains of quartz and feldspar
Nav.....	26	Quartz coated by glauconite, round grains of glauconite with small grains of magnetite regularly arranged, also mica, hornblende, and pyroxene
Haz.....	6	Composed of glauconite grains more or less altered; some grains appear to be concretions, while others look as if they may be sections of Foraminifera
Nav.....	28	A feldspar grain covered by fibrous glauconite
Red.....	13	Alteration to hematite and to limonite

[1] Nav. = Navesink; Mat. = Matawan; Haz. = Hazlet Sand; Red. = Redbank.



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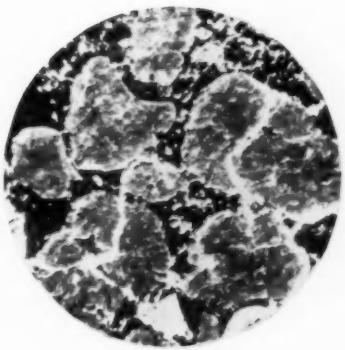

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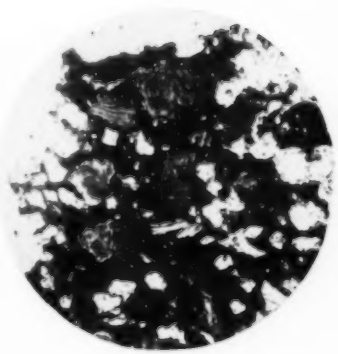

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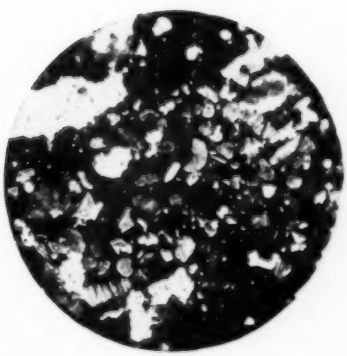

4

Some photo-micrographs are given (by way of illustration) which were taken of some slides of glauconite.

No. 1 is taken from material from a greensand pocket in the Redbank, and is intended to show glauconite grains highly altered.

No. 2 is taken from the clay ironstone of the Navesink, and shows fresh glauconite grains. The dark spaces between the grains show the ground-mass of limonite and clay.

No. 3 is also taken from the clay ironstone of the Navesink, and is to show fibrous glauconite.

No. 4 is taken from a sample of Hazlet Sand from near Cliffwood, N. J. It shows fibrous glauconite, and also the size and shape of some of the glauconite grains.

The diameter of the field of the microscope, when these photo-micrographs were taken, was 2.55^{mm}. In the slide from which No. 2 was taken two grains of glauconite were measured, one of which was 1.3^{mm} long and 0.65^{mm} wide; and the other was round and 0.2^{mm} in diameter. Some grains are smaller than this, down to 0.1^{mm} or less, but they are not so common, and the average grain is much larger than 0.2^{mm}.

THE MESOZOIC OF SOUTHWESTERN OREGON[1]

GEORGE DAVIS LOUDERBACK
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[1] This study was made as research assistant of the Carnegie Institution of Washington, and is published by permission of the Institution. Read before the Cordilleran Section of the Geological Society of America, December, 1904.

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INTRODUCTION

During the summer of 1904 the writer, in the course of an investigation of the glaucophane schists of California, made a trip into southern Oregon for the purpose of comparing the geological relations of the schists reported as occurring there with those of similar rocks in California. In particular, the Oregon schists were said to occur in a formation corresponding to the Knoxville and Horsetown of California, and were considered as contact products of irruptives which were intruded into the formation, and were therefore considered at least post-Horsetown in age. In California, on the other hand, similar schists are found in the Franciscan, a thick and important series of formations which underlies the Knoxville unconformably, and the greater part of whose basic intrusives, if not all, are pre-Knoxville in age. No schists have yet been found in the California Knoxville or later rocks. It would be of considerable interest, then, to the student of petrographical provinces, if such rocks, which are apparently due to rather uncommon conditions, and which in the United States are, so far as known, limited to this coastal (California and Oregon) region, had been developed in different parts of this territory in formations which differ both in age and in lithologic characters, and in relation to igneous rocks of apparently different ages of intrusion.

The study of the field relations of the Oregon schists, however, have led to the conclusion that they were developed in formations of the same age and lithologic characters, and have the same associations and relationships, as the corresponding schists in California. At the same time, certain important features of the Mesozoic stratig-

raphy and history of the region were recognized, and a closer correlation between the geological conditions and sequence in southwestern Oregon, and those of the California Coast Ranges, made possible. To set forth these general results is the purpose of the present paper.

HISTORICAL

The region under discussion lies in southwestern Oregon, and is included from east to west between the western foothills of the Cascade Range (long. 123° west), and the Pacific Ocean (about 124° 20′ to 124° 30′ west); and from north to south between the latitude of Roseburg or the head of Coos Bay (about lat. 43° 15′ north), and the Klamath[1] Mountains (about 42° 30′ north). This field has been studied by few geologists. Dana and later Newberry, in their exploration work in the early days, saw but little of the country, and were hardly in position to arrive at any definite conclusions as to even the major events in the geological history of the region. Mr. G. F. Becker,[2] about 1890, studied some of this country in the vicinity of Riddles in conjunction with Mr. W. Q. Brown, and arrived at certain conclusions that were important in extending the knowledge of the Pacific coast Cretaceous. It is to Mr. J. S. Diller, however, that we owe by far the greater part of our present knowledge of southwestern Oregon. He has spent a number of years in the investigation and mapping of considerable areas, and his studies have covered all parts of the region outlined above. His general results are presented most systematically and with the greatest detail in the texts accompanying the Roseburg, Coos Bay, and Port Orford folios[3] of the *Geologic Atlas of the United States*, although certain features are more particularly treated in various memoirs, a number of which will be referred to in the body of this paper.

AREAS STUDIED

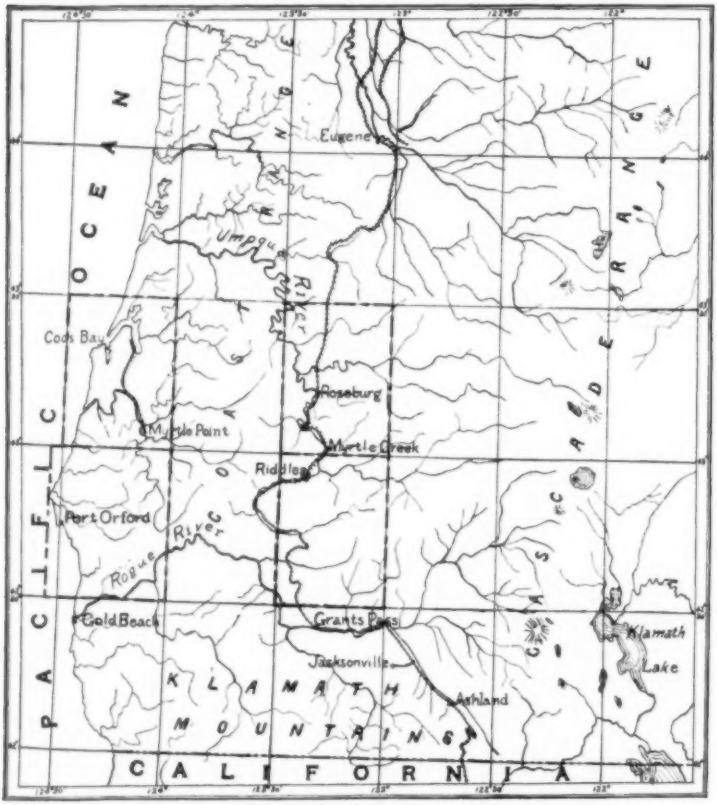
The index map, page 518, shows the relative positions of the three geologically mapped quadrangles of southwestern Oregon—the Coos Bay and Port Orford lying in contact on the coast, and

[1] For use of this term see p. 552.

[2] *Bulletin of the Geological Society of America*, Vol. II (1891), pp. 201–6.

[3] U. S. Geological Survey, *Geologic Atlas of the United States*, Folios Nos. 49 (1898), 73 (1901), and 89 (1903).

the Roseburg somewhat inland and in the latitude of the Coos Bay area. Of the Riddles quadrangle which adjoins the Roseburg on the south, and corresponds in latitude to the Port Orford, only a topographic sheet has been issued. It will be noted that these two



INDEX MAP OF SOUTHWESTERN OREGON
The areas of the Geological Survey quadrangles are inclosed in heavy broken lines.

pairs of quadrangles are separated by a strip, one quadrangle in width. This unmapped area represents what is known as the Oregon Coast Range which runs north and south, and is broad enough to occupy the unmapped strip and extend its foothills a short distance into the Roseburg area on the east, and into the Coos Bay and Port

Orford areas on the west. Within this region the Coast Range is made up almost entirely of Eocene rocks, and is, therefore, not of particular interest in the present investigation; but in the country both east and west of this range the Eocene sediments have been largely stripped off, and considerable areas of the pre-Tertiary rocks exposed. These in general have a trend from northeast to southwest, cutting obliquely across the Roseburg quadrangle, passing under the Eocene sediments of the Coast Range, emerging with a similar trend on the west side of the range, and continuing to the ocean. The writer's studies were practically confined to the southern parts of the two northern quadrangles and the northern parts of the two southern quadrangles.

PRESENT KNOWLEDGE OF THE MESOZOIC OF THIS REGION

THE MYRTLE FORMATION

Diller has included most of the Mesozoic of this region in the "Myrtle formation." This name was originally given by him to the Mesozoic of the Roseburg quadrangle (published in 1898), because of the fact that it is most typically developed along Myrtle Creek in the southern part of that area, and because in that vicinity was found the greatest range of fossils. The lower part of the Myrtle formation at that locality is stated to be characterized by *Aucella piochi* and *A. crassicollis*, and to correspond, therefore, to the Knoxville (a part of the Lower Cretaceous) formation of California. The upper part is said to be characterized by *Pecten operculiformis*, *Trigonia æquicostata*, and other forms of diagnostic value, indicating that it is of the same geological horizon as the Horsetown beds of California (Lower Cretaceous), including the uppermost horizons immediately below the base of the Chico.

Certain rocks lying southwest of the limits of the Roseburg quadrangle are provisionally referred to the Jurassic, with the statement that they may possibly extend onto the quadrangle; and some cherts occurring within the quadrangle are also made doubtfully Jurassic; but these are both distinctly separated from the Myrtle formation and discussed under a different heading. Moreover, a considerable gap is noted between the Myrtle and the Umpqua (Eocene) formations, and is said to correspond to the Chico (Upper Cretaceous) of California and other parts of Oregon.

It would appear, then, that the "Myrtle formation" as originally described has very definite limits, running from the base of the Knoxville to the top of the Horsetown—an interval named in California the Shasta group by Whitney as early as 1869.

In 1901, Diller referred the pre-Eocene rocks of the southern part of the Coos Bay quadrangle to the Myrtle formation, although no fossils were found in them within the limits of the quadrangle. The nearest fossil localities are some miles south of the southern boundary, and indicate a Knoxville age. Cherts with the same relationships as those of the Roseburg quadrangle are here referred doubtfully to the Cretaceous, but they are not included in the Myrtle formation.

In the Port Orford folio (1903) considerable areas are mapped as Myrtle. This term, in general, has the same significance as in the former publications, and is treated under the Cretaceous. The occurrence of some small areas of Jurassic within the areas mapped as Myrtle is indicated by fossils found in float material, but their occurrence *in situ* could not be determined. There were also some small patches of rock found which contain Chico (Upper Cretaceous) fossils. Almost the whole of the area mapped as Myrtle, however, is described as corresponding to the Myrtle of the original localities in the Roseburg quadrangle, that is, to the Shasta group of California. The wording of some parts of the text, however, make it doubtful whether Diller intended to retain the same limits for the Myrtle formation as was determined in the type locality, or whether he would extend the term to include whatever Upper Cretaceous (Chico) were present, and make it equivalent to the Shasta-Chico series of California. If such had been the intention, it might be expected that the term "Myrtle series" would have been used as comprehending so many groups of formations. It may be added that the cherts of the Port Orford quadrangles, which have the same geological relations as those in the other two quadrangles, are here included in the lower (or Knoxville) part of the Myrtle, so that even with the original limits the term "formation" seems very inadequate, and is likely to produce an incorrect conception of the complexity of the Myrtle.

As the Chico areas are but one or two small spots in the Port

Orford area, none having been yet reported for the other two quadrangles, we may consider the Myrtle formation of Diller, as defined by its original limits, to include those strata from the basal Knoxville to the uppermost Horsetown, that is, to be equivalent to the Shasta group of the California Cretaceous.

OUTLINE OF MESOZOIC AND RELATED HISTORY

In the text accompanying the Port Orford folio Diller gives a general sketch of the events of the geological history of that and related areas, and, as the most recent summary of our knowledge of this region, it may be well to consider in outline the chief events there given which relate to the Mesozoic history, its beginning and end. Arranged in historical order, these are:

1. Ancient sea in which Colebrooke schists were deposited	Pre-Cretaceous. Pre-Devonian?
2. Interval between Colebrooke deposition and that of the "Lower Cretaceous Myrtle formation."	In part Jurassic, including.
2.*a* (Upper Jurassic deposition indicated, the Klamath Mountains probably submerged.)	Late Jurassic.
3. Upraising of Klamath region; coast moved westward beyond present position (probably to margin of continental plateau); important mountain-forming epoch.	Post-Jurassic. Pre-Myrtle. (Pre-Knoxville.)
4. Subsidence, the sea advancing inland until most or all of Klamath Mountains were covered, and waves swept the foot of the Blue Mountains in eastern Oregon, and the Sierra Nevada of California.	Lower Cretaceous. (Myrtle) period. (Shasta.) Continued into Chico.
5. Folding, crushing, intrusion of igneous rocks, and whole raised above the sea; extensive erosion, the Chico being removed except one or two small patches.	Chico in part? and Cretaceous-Eocene interval.
6. Subsidence and marine deposition.	Eocene.

THE HETEROGENEITY OF THE MYRTLE FORMATION

It will be noted that in the above outline the Myrtle formation is considered as representing a period of continuous marine sedimentation, and the igneous intrusives with which it is so abundantly supplied are considered post-Myrtle, indeed post-Chico; that is, post-Cretaceous. And this is the idea which underlies all the descriptions of the Myrtle, both of this and the other quadrangles. The results of the writer's field studies, however, are to the effect that

the formations mapped as Myrtle, *sensu stricto*, may be separated into two chief groups or series, each representing quite an extent of geological history, and separated from each other by a distinct interval during which there were various intrusions of igneous rocks, and a period of considerable erosion. In other words, the Myrtle formation is a sort of complex, consisting of heterogeneous parts. Its lower division shows more marked variations in characters and geological history, and probably represents the greater period of time. No word short of "series" seems to represent its thickness and variations. The upper part, if we define the top of the Myrtle as the top of the Shasta group, might very properly be called a group, but if we extend it to include the Chico, it would better also be called a series.

The lithologic characters of the two divisions differ considerably and will be described first.

THE LITHOLOGIC CHARACTERS OF THE SEDIMENTARY ROCKS

THE LOWER SERIES

General composition.—The lower series is made up of the following marine deposits in order of their relative abundance: sandstone, shale, conglomerate, chert, and limestone.

The sandstone.—Sandstone is by far the most abundant rock in this series, and is generally a gray, well-lithified rock, which, on account of its silicious cement, breaks across the grains in such a way that they do not stand in relief on a freshly fractured surface. The material of the grains is of an arkose nature, showing abundant feldspar, etc., and this, combined with its degree of lithification, makes it sometimes, to the naked eye, have a remarkable likeness to an igneous rock. This may be further augmented by the fact that the sandstones have suffered considerable squeezing and crushing, the bedding planes being frequently very difficult to determine, and, if determinable at some point, can generally be traced but a short distance. Large exposures often occur where the sandstone has a thick-bedded or massive appearance, and the only planes determinable are numerous irregular ones of fracture. Not infrequently the pressure to which they have been subjected has flattened the grains along definite planes and caused some recrystallization of

the constituents, and occasionally an actual schist has been locally produced.

Besides the development of a silicious cement, much of the sandstone is intersected by small and irregular quartz veinlets. These are sometimes quite abundant, and occasionally larger veins some inches across, or irregular bunches of quartz, are developed. Secondary calcite in small veins or irregular grains, etc., is also found.

Some of the more silicified sandstone stands out in hard and rather fresh exposures, while other parts weather down, assuming a brownish color. Its general massiveness, folded and crushed condition, and other properties make the determination of structural features and measurements of sections exceedingly difficult. Occasionally thin and distinctly bedded sandstones are found which may be considerably less altered than those above described. They are not characteristic, and are generally not traceable any great distance.

The shales.—Shale occurs in subordinate amount associated with the sandstone. It varies in color, being usually a rather pure gray, more rarely greenish-gray, and is generally much crumpled, crushed, broken, and slickensided, although exposures of less disturbed material do occur. Occasionally it takes on a hard, slate-like habit and shows distinct cleavage planes; again, it is so crushed as to show no planes at all. Some parts show irregular secondary silicification, while others seem very slightly altered.

Conglomerates.—Conglomerate lenses are met at a number of places and at apparently different horizons, but they can rarely be traced very far and seem to be of little value in subdividing the series into groups. They are frequently of jasper, quartz, and some other pebbles. These pebbles are generally firmly cemented, so much so occasionally that a fragment broken off by a hammer will show a rather even fracture face passing through both pebbles and matrix, the pebbles neither protruding nor breaking out, and leaving rounded depressions. Faulted pebbles are quite common.

Cherts.—Lenses and irregular masses of radiolarian chert are very characteristic of the lower series. Along the coast quadrangles they may be more abundant than the conglomerates, but in the Roseburg quadrangle they are apparently less so. On account of their hard silicious character, bright colors, and great resistance to weathering,

they form very prominent exposures, and are likely to appear more abundant than they really are.

These cherts are of a prevailing red color, but may be perfectly white or green, brown, yellow, or gray—sometimes variegated. They are generally distinctly stratified, the silicious layers varying from an inch or two to a foot or more—two to four inches being the more common values. These are separated by a peculiar, generally dark red ferruginous shale, varying in thickness from little more than a film between the chert layers up to an inch or more. Several hundred alternations of cherty and shaly layers may occur in a single exposure. These layers are sometimes badly crumpled, and not infrequently, in the smaller masses, the stratification may be almost or entirely obliterated.

Small, clear chalcedonic spots are frequent indications of original radiolaria, and sometimes more or less of the structure or ornamentation of the original test is preserved. The bulk of the silicious layers are, however, apparently recrystallized and are very fine-grained (microcrystalline) quartz aggregates. These layers are also traversed in all directions by minute quartz veins.

The cherts occur either as lenses in the sandstones or as inclusions in the basic igneous rocks which cut the lower series.

Limestone.—The only limestone noted occurs in a series of lenses described in the text of the Roseburg folio as the Whitsett limestone lentils. These are in general gray and massive, showing more or less the effects of crushing, and, while some recrystallization is present, there has not been any noteworthy development of a phanero-crystalline-granular structure in the larger lenses at least. Some of the smaller areas appear to be more altered and to have developed a fine-grained to compact crystalline structure. The more altered ones show an abundance of calcite veinlets up to about two inches in thickness. They are also traversed irregularly by a secondary pink chert which shows the effects of fracturing since its formation. The matrix is sometimes colored variously, yellow, brown, etc.; the veins are generally white. In some parts oölitic structures were observed, and in some the more or less abundant remains of microscopic organisms—foraminifera in the calcareous parts, and, in the associated chert, apparently radiolaria.

THE UPPER GROUP

General composition.—In lithologic characters the upper group differs considerably from the lower. The most abundant and characteristic rock type is shale, then sandstones and conglomerates. No trace of radiolarian cherts or cherts of any type, occurs in this group, nor do foraminiferal limestones corresponding in general character to the Whitsett lenses, although there are calcareous shales.

The most striking general difference between the lower and upper divisions is the markedly inferior lithification of the latter. Although it has been compressed into large folds, and to some extent faulted, and even locally crushed, especially where it has been thrust against the more massive older rocks in the course of its folding, yet, in general, its lithologic characters have been comparatively little altered.

Shales.—The shales, which are the predominating rock type, are characteristically of a greenish-gray color, sometimes pure gray, and their stratification and lamination, except occasionally where locally crushed, are always readily discernible, and the dip and strike meas urable, and the beds and structures may be traced for considerable distances without great effort. No slaty structures are developed, and hardened facies are rare. A spheroidal structure is not uncommon, but the original lamination is always distinct. Moist samples of these shales smell strongly of clay.

The shales are commonly more or less calcareous, and some are highly so and may be called argillaceous limestones.

Sandstones.—Interbedded with these shales are rather thin-bedded sandstones from two or three inches up to not generally over several feet thick, though occasionally heavier beds occur. They are commonly brown, sometimes buff or greenish, and never show the peculiar gray compact facies so often seen in the sandstones of the lower series. In some parts of the series the shales greatly preponderate over the sandstones; in others they may be in about equal quantity, or occasionally the sandstones may actually prevail. On account of their general thin-bedded character and the regularity of the bedding, the attitude of these sandstones can generally be readily determined and measured.

The material of which the sandstones are composed is, as in the

lower series, rather arkose, but, while some of the beds may be quite hard, the induration, in general, has been much less than in the lower sandstones. On a surface of fracture the grains stand out in relief and the clastic character is always readily recognizable. The excessive fracturing and crushing found in the lower sandstones is absent, and the beds maintain their individuality and distinctness for considerable distances, although the thin beds, being lens-like in nature, are less persistent than the structures—folds, etc.—which latter may be traced for many miles. With the absence of the abundant fracturing and of the cementation characteristic of the lower series may be associated the practical non-existence of quartz veins, veinlets, or masses in the upper group. Small calcite stringers are sometimes found, but only rarely a slight local development of secondary silicious material in small veinlets. Phases where the individual grains are flattened into an incipient schistose structure, and actual development of recrystallized facies, were nowhere observed.

Conglomerates.—Conglomerates are rather more common than in the lower series, and are quite indurated and show faulted pebbles. With the exception of showing less the effects of squeezing and crushing, they have very much the general appearance of the conglomerates of the lower series. While very largely made up of chert pebbles, they frequently carry pebbles of some of the other rocks which occur in the lower series, as will be explained later.

The conglomerates occur chiefly in the lower part of the upper group. It is possible that one may be found that marks the beginning of the Horsetown epoch of deposition. However, no attempt was made to discover such a stratigraphic boundary for those beds. Of great interest in determining the relationships of the two major divisions is the heavy basal conglomerate of the upper group—over a thousand feet thick—which in the vicinity of Myrtle Creek can be traced for probably twenty miles or more. This will be more fully described later on.

THICKNESS OF THE SEDIMENTS

The upper division.—The thickness of the upper division is perhaps most simply and satisfactorily measured in the vicinity of Myrtle Creek. It is here folded into a syncline which may be traced

for many miles. The lowest horizon for a number of miles is a conglomerate, and the range of fossils indicates that the complete series is represented up to the top of the Horsetown horizon. Diller has estimated the thickness at about 6,000 feet, and the writer's observations confirm this figure as a good approximation.

The lower division.—Unfortunately, the lower series is so broken, and its stratigraphy so obscure, that it was not found practicable to measure its thickness, but the fact that it has been more strongly disturbed than the upper division, and yet covers larger areas in which it has been deeply dissected by streams without exposing the underlying rocks, would seem to indicate that it is at least as thick as, and probably thicker than, the upper group.

PALEONTOLOGIC CHARACTERS

The upper division.—The upper group has yielded a considerable amount of fossil material. Its lowest beds are characterized by the presence of *Aucella piochi*, the characteristic fossil of the lower Knoxville in California, and, as higher beds are examined, they show, in order, fossils of the upper Knoxville and of the Horsetown, as already described on p. 519. In fact, all of the fossils described in the texts of the Roseburg and of the Port Orford folios (no Mesozoic fossils were found in the Coos Bay quadrangle) as characteristic of the Myrtle formation, indeed all fossils described as occurring in the Myrtle formation except the radiolaria of the cherts and the imperfect shells in the Whitsett limestones, occur in the upper group of formations.

The lower division.—The lower or semi-metamorphic series is almost destitute of fossils, except the minute remains of radiolaria, etc., in the cherts and limestones, and these do not definitely indicate the horizon. In the limestone lentils Diller has found a "few, generally imperfect fossils" in which Mr. T. W. Stanton has recognized *Opis californica* and "a species of *Hoplites*, either closely related to or identical with *Hoplites dilleri*." As there is apparently some doubt about the determinations, and as the range of the above fossils is not known, it cannot be said that they indicate the age of these beds with any definiteness, although we may accept them as showing that the limestones are probably Jurassic or Lower Cretaceous. The position of this series, however, stratigraphically below the base of the upper

group, whose range is rather definitely determined by the contained fossils, fixes its upper limit and places the whole series below the base of the Knoxville—the zone of *Aucella piochi*—from which it is separated, as will be shown later, by an unconformity.

TERMS USED

Definition of the Myrtle group.—In discussing and describing further the characteristics of the two well-defined and distinctly separable groups of formations, it would conduce to simplicity and clearness to give them names. If we define the Myrtle in terms of the stratigraphic limits set by Diller and determined by characteristic fossils, as that continuous sequence of beds whose base is the zone of the *Aucella piochi*, and whose summit corresponds to the topmost beds of the Horsetown group, then the Myrtle corresponds exactly to the upper group above described. It is proposed, therefore, to use the name "Myrtle group" for the formations so described, and this term is particularly appropriate, as a most simple and complete development of the Myrtle group occurs along Myrtle Creek and about the town of that name—Diller's type locality. If it should seem better to extend the limits of the Myrtle to include the Chico equivalents, as is perhaps Diller's intention in the Port Orford area, the term "Myrtle series" would seem more appropriate.

The Dillard series.—For the lower series, which, while it has been mapped as Myrtle, is entirely below the stratigraphic limits set for that group, the name, "Dillard series" will be used, after a village, on the railroad, situated in the midst of the largest area of this series on the Roseburg quadrangle. This series has already been characterized stratigraphically and lithologically, and will be more concisely defined later.

IGNEOUS AND METAMORPHIC ROCKS ASSOCIATED WITH DILLARD SERIES

General characters.—The Dillard series is abundantly supplied with igneous rocks which are found at frequent intervals, especially in the areas of the coast quadrangles, cutting it irregularly in all directions. Most of these rocks are quite different from the igneous rocks of any of the later formations and are, indeed, characteristic of the Dillard series. They are so varied and irregularly mixed, and

commonly so badly weathered, that their detailed study, especially that of the basic series, would require considerable time. Only their more striking characteristics and more evident field groupings are given here.

The basic series.—The igneous rocks included under this heading are the most abundant, the most varied, and the most difficult to study of any in the region. In the text of the Roseburg folio they have been described under the title of metagabbro. In the Coos Bay map they are incorrectly grouped with the Eocene basalts, and given the same color and letter symbol, although in the text it is stated that certain of the areas are "more highly altered than those already noted, and are associated with the Myrtle formation. They are probably of greater age than those found in the Pulaski formation[1] and are the product of eruptions occurring at the close of the Cretaceous."[2] In the text of the Port Orford folio they are separated into two groups, and described as gabbros and basalts, respectively.

Within the basic series are rocks that are petrographically different, but are probably genetically related. On the other hand, there are included rocks that are not closely related. The briefness of the writer's study does not allow of a satisfactory genetic subgrouping or a complete detailed description of these rocks, but certain general characteristics and more obvious groupings may be given.

The greenstones.—A very characteristic field type in the Dillard series is rather fine-grained, frequently compact, the grain generally not being discernible to the naked eye, and of a dull green color weathering to brown. While sometimes producing prominent outcrops, these rocks frequently weather down to a brownish earth, resembling on superficial examination the weathering products of the sandstones, and the boundaries of their areas then become frequently difficult, or at least require considerable time, to determine; indeed, small areas may easily be overlooked entirely. In texture these rocks vary from compact—perhaps sometimes originally glassy—to fine granular or fine diabasic. The normal or average type may be called basaltic, consisting essentially of pyroxene and

[1] A division of the Eocene of the Coos Bay quadrangle.

[2] Cretaceous was there used as a synonym for Myrtle, and should now read Dillard, as they were undoubtedly erupted before the deposition of the basal beds of the Myrtle group.

basic soda-lime feldspars with magnetite, etc. This is varied, however, by the partial or even complete substitution of more or less hornblende for the pyroxene, or by the more or less complete disappearance of the feldspar. Alteration is generally very marked, chlorite, calcite, limonite, and kaolin, being common products of the changes; and the rocks are frequently crushed, sheared, slickensided, and traversed by calcite veinlets.

The exact relationship of these rocks to the Dillard series can, in the majority of cases, not be determined, and some of the bodies may represent contemporaneous lava flows. Proof of this was not found in any individual case, but in many areas the fact of intrusion into the sandstones, and especially the cherts, with small apophyses breaking through and spreading between the layers, is perfectly evident. All of these rocks may therefore be intrusive. Some, however, apparently have an original clastic structure and may be tuffs. They are called basalts in the text of the Port Orford folio, but as they vary so much in texture and mineral composition, and as their textures, mineral composition, and exact geological relations are frequently indeterminable in the field, and, finally, as the almost uniform green coloration, especially on a fracture surface, is so universal, the writer has used the comprehensive field term "greenstone" as more expressive of these characters and variations.

The feldspathic granular rocks.—The rocks discussed under this broad title include those described as "metagabbros" in the text of the Roseburg folio (except such as have been described above as greenstones), and the "gabbros" of the Port Orford quadrangle. This is evidently a genetically heterogeneous group, which the briefness of the writer's study has left in a very unsatisfactory state. We may distinguish, however:

a) A group of basic gabbros which are genetically related to the serpentines (altered peridotites, to be described later). These rocks are generally essentially coarse granular holocrystalline aggregates of diallage and a very basic soda-lime feldspar, with various accessory minerals, and from their close association with the serpentines in the field, and the habit of their component minerals and the intermediate forms which exist, they have presumably been derived from the same magma which gave rise to the serpentines.

b) A group corresponding in range to the greenstones described above. They include granular and coarse diabasic rocks made up essentially of pyroxene and a moderately basic soda-lime feldspar, which may perhaps be taken as the average or normal type. The pyroxene is in some forms replaced by hornblende, giving rise to dioritic rocks. These are apparently, sometimes at least, differentiation products, and they may sometimes be due to secondary alteration of the original pyroxenes, as indicated by the term "metagabbro" used in the Roseburg folio. The limit of variation in this group—considered as a genetic group—has not been determined. It may, and probably does, include more acid and more basic members than above described.

This group of coarse-grained rocks may be genetically related to the greenstones already described, and it parallels them very closely in mineral composition, and also in bulk chemical constitution, as shown by the analyses given in the text of the Port Orford folio. Types of intermediate grain also exist and may be considered as physical gradations between the coarse-grained and the greenstone series.

The members of this group are, as far as observed, all intrusive in the Dillard series.

c) A third group, which is probably genetically distinct from the one just described, may be called the quartz-diorite-diorite group. These rocks are granitic in habit and structure, and have as their essential constituents a more acid soda-lime feldspar, hornblende, commonly quartz, and sometimes biotite. Chemically, according to the analyses given for the Port Orford material, they appear to vary from perhaps 50 to 60 per cent. in silica, to be rather low in lime and magnesia (from about 4 to 6 per cent. and 2 to 3 per cent. respectively), and high in alkalies (about 7 per cent. or over). The abundance of original quartz in some of the sections studied would indicate that the maximum silica percentage is above that given in the analyses, and the rocks are very decidedly quartz-diorites—the quartz sometimes making up a third or more of the section. They are classed as acid types of the gabbro group in the text of the Port Orford folio, but in habit, texture, mineral, and chemical composition appear to be more closely related to the diorites and quartz-diorites which are

so abundant and well known in various parts of northern and central California. They are therefore provisionally placed in a group by themselves. Their relationship to the Dillard series was not definitely determined. As typical pebbles were found in the Myrtle conglomerate, they are undoubtedly pre-Myrtle.

The ultrabasic rocks.—Serpentines occur abundantly in all of the major areas of the Dillard, sometimes in large masses or elongated areas traceable for miles, frequently in small patches or dikes down to exposures a few yards across, scattered irregularly through different parts of the series. The small dikes do not appear to have any close spacial relationship to any larger or more central masses, but occur sporadically and independently at any point of the areas. Where not badly disturbed, or on fresh fracture of less altered masses, these rocks are dark-—almost black, with a brown or green tinge. Most of the material has undergone considerable movement, and is filled with shear zones and slickensided surfaces, with bowlder-like residual masses in greater or less abundance which show the real texture on breaking. The serpentine has generally a more or less massive structure to the eye and was largely derived from olivine. Fresh fractures show, as a rule, a generous sprinkling of foliated crystals, with a pearly to almost metallic luster, and with the appearance of phenocrysts in the compact-looking ground. These are sometimes distinctly bastite, and then presumably derivatives of enstatite or a similar rhombic pyroxene; at other times the more or less altered original pyroxenes—enstatite or diallage. These pyroxenes may locally make up the entire mass and produce pyroxenites. Other transitions occur to a feldspathic rock, and the gabbros described above under (*a*) appear to be differentiation products of the magma which gave rise to these serpentines.

As the serpentines are very resistant to weathering, and give rise to very little soil *in situ*, the greater masses are generally bare of vegetation, and the larger areas, which frequently form hills or ridges, give striking exposures easily traceable by the eye at a distance. The small dikes, however, frequently cause sliding in their vicinity, and are more or less covered with débris from topographically overlying formations, so that they produce very inconspicuous exposures, and their presence and extent may become very difficult to determine.

The serpentine dikes cut into and through the members of the basic series—both coarse-grained rocks and greenstones. This relationship has been observed at a number of different places both in the Roseburg area and in the coast quadrangles.

The dacite-andesite group.—The rocks of the dacite-andesite group are much less abundant than any of the above described igneous series, but they occur at intervals on the Roseburg, Riddles, and Port Orford quadrangles, and show but a comparatively small range of characters throughout these areas. They present in general a rather compact groundmass, which differs from the other fine-grained rocks associated with the Dillard series in its usual pale colors, light yellowish, slightly pink, or white, and in its superior hardness. The most common type shows phenocrysts of quartz corroded by the magma, and a soda-lime feldspar, usually more abundant than the quartz. Ferromagnesian minerals are rare as phenocrysts and of very subordinate development (usually hornblende) in the groundmass. One common type has a fine, even grain, appearing to the eye as if without porphyritic structure. In general appearance it resembles quartzite. Under the microscope, however, its relationship to the distinctly porphyritic types is readily recognized. Analyses given in the text of the Port Orford folio show about 70 to 75 per cent. silica, 4 to 7 per cent. soda, and 2 to 2½ per cent. potash. Both chemically and in mineral composition they belong with the dacites.

A number of the specimens examined exhibit the same structures and general appearance as described above, but with no visible phenocrysts of quartz. In thin sections made of some of these no quartz could be found either as phenocrysts or in the groundmass. Although none of these were analyzed chemically, they may be referred to the andesites. As they are closely related to the dacites in the field, and show gradational forms carrying varying proportions of quartz, the two mineralogical types are considered to be genetically related and placed in a dacite-andesite group.

The rocks of this group occur in small irregular bunches and in elongated, dike-like masses in the Dillard series, and not uncommonly within the serpentines which they appear to cut. They are described and mapped in the Roseburg folio as "dacitic rocks," and in the Port Orford folio as dacite-porphyry.

Glaucophane and associated schists.—A striking feature of the Dillard series is the irregular and sporadic occurrence of small bodies of schists, certain types of which are characterized by the presence of glaucophane. The variations in these schists, due to the presence or absence or varying proportions of quartz, mica, glaucophane, actinolite, and other amphiboles, garnets, epidote, chlorite, and many other minerals, is very great, and it would lead too far, for the present purpose, even briefly to characterize the different petrographical types which are rather numerous in comparison with the areal importance of the rocks. These schists are generally associated with various more or less basic igneous rocks, and have been considered as products of contact metamorphism. The fact of prime importance for the present consideration is that no outcrop of these schists has yet been discovered in the Myrtle areas, while small patches are of frequent occurrence in all areas of the Dillard.

RELATIONS TO THE MYRTLE GROUP

General relations.—While the rocks of the Myrtle group frequently lie in contact with the different groups of igneous rocks just described, careful search failed to bring to light any definite evidence of an intrusive relationship. In every case the beds in contact with the intrusives were apparently deposited upon the surface of the latter, which must have been previously exposed by erosion. No traces of tuff beds or lava flows were found anywhere in this group.

General comparison with the Dillard.—If the areas of the Dillard had been mapped separately from those of the Myrtle, probably the most striking differential characteristics that would have been evident to a student of the folios are the practically entire lack of igneous exposures within the lines of the Myrtle group, while the Dillard areas are broken up and cut through again and again by dikes and masses of the most variable shapes and sizes. The Myrtle area most particularly studied by the writer is the type locality lying along Myrtle Creek and extending a number of miles down through the Riddles quadrangle. Here, as far as observed, igneous rocks are entirely absent from the Myrtle area, except along its edges, where they form the contact for a number of miles. Occasionally near the edge of the syncline a small area of igneous rock appears within the Myrtle boundaries and elongated in the direction of the axis of

folding. No trace of contact phenomena was observed in the soft shales or the conglomerates, and these exposures appear to be due to faulting along the line of the structural axis, bringing some of the "rim" rock to the surface.

The Myrtle conglomerate.—In this area the lowest beds carry fossils that are characteristic of the base of the Myrtle and a heavy basal conglomerate rests on the surrounding igneous rocks. This conglomerate is evidently the result of long-continued grinding together of the component rock fragments, for the material of the Dillard formation has been worked over to such an extent that the rock types appear in no wise in proportion to their relative areal abundance, but apparently mainly in proportion to their relative resistance to abrasion.

The cherts are the most abundant pebbles, the dacites (and andesites) next. In some localities the latter are more abundant than the former. They show the same textures, mineral composition, range of variation of characters, and general appearance as the Dillard dacites and andesites, and are undoubtedly the same. The characteristic Dillard sandstone is but sparingly present, as also are the types of the granular basic rocks. Some characteristic quartz-diorite pebbles were found, but greenstone pebbles are exceedingly rare, and glaucophane schist, serpentine, and shale were not found at all. Of these it may be remarked that the greenstones are usually badly decomposed and crushed; the schists occur only in small quantity and are readily disintegrated on account of their fissility; and the serpentine and shales are more or less soft and generally friable.

Other evidence.—The relationships of the above-described igneous rocks are in general so evident that even without the testimony of the Myrtle conglomerate they would be referred to pre-Myrtle eruptions. The serpentines, however, are rather noncommittal. They lie on the Myrtle contact for several miles, and yet are unrepresented in the basal conglomerate. But their absence from this conglomerate appears to be satisfactorily accounted for by the considerations presented in the last paragraph. They are here referred to the pre-Myrtle because they occur so frequently as dikes and masses throughout the Dillard, while they are found only on the

border of the Myrtle areas without any evidence of contact action on the practically unaltered shales; and more particularly because they are apparently intruded by the dacites and andesites which are abundantly represented in the Myrtle basal conglomerate and which are evidently pre-Myrtle. The intrusion of the serpentines by the dacitic rocks is claimed by Diller both in the Roseburg and the Port Orford areas, and such observations as the writer was able to make are in accord with his results.

The absence of glaucophane and other related schists from the Myrtle areas, which was stated above on the basis of field observations, may be theoretically correlated with the pre-Myrtle age of the igneous rocks with which they are so frequently associated.

SUMMARY

We may conclude, then, that the time represented by the inter-Dillard-Myrtle interval (perhaps including part or even all of Dillard time) was a period of great igneous activity. On the other hand, during Myrtle time the practically continuous sedimentation was uninterrupted by volcanic eruptions, and even the inter-Myrtle-Arago time interval, although representing a period of uplift and considerable erosion, shows no evidence, in the areas studied, of igneous activity. Vulcanism apparently lay dormant in this province until the Tertiary, when, in the Arago (Eocene), the period of quiescence was terminated by the intrusion and outpouring of basalts and diabases.

ECONOMIC RELATIONS

Purpose of the discussion.—A discussion of the economic geology of this province *per se* would be inappropriate to the purpose of the present paper, but a brief statement of the economic relations may be of some value in bringing out more clearly the contrast in characters between the Myrtle and the Dillard, and the difference in the geological agents and processes to whose activities they have been subjected.

THE MYRTLE GROUP

As far as known to the writer, nothing in the way of ore deposits, veins, mineralized zones, contact areas, or other like phenomena has been observed in the rocks of the Myrtle group. Sedimentary products of special economic value, such as coal, gypsum, iron ores,

etc., have practically not developed at any point. At the time of the writer's visit an oil well was being sunk near the village of Myrtle Creek, and not far from the median line of the Myrtle Creek syncline; but it had not yet proved of any value. Similar formations in California have yielded some oil, but are not economic producers.

The sandstones, on account of their general regularity of bedding and fair amount of induration, lend themselves to quarrying and building, and have been used to some extent. The majority are too thin-bedded for this purpose.

As the conglomerates of the Myrtle were formed after the veination of the Dillard and of the Klamath Mountains schists, it is quite probable that in places they carry placer gold, etc. However, on account of the induration of these conglomerates, the concentration of values may never be found high enough to prove of economic value.

THE DILLARD SERIES

General contrast.—In contrast to the above, the Dillard series carries a considerable variety of economic products, especially the results of secondary agents, even though the actual quantities are apparently nowhere in such proportions as to allow of the development of large properties.

Quartz veins.—As has already been said, quartz veins and veinlets are rather characteristic of the Dillard series. The veinlets are very common in the cherts, and in the sandstones, especially near igneous rocks. In general, these are not known to carry "values," although in the sandstones and the igneous rocks they grade into veins which do.

On South Myrtle Creek veins in the "metagabbro" have been found to carry gold, etc., in sulphuret-bearing quartz, and one or two small mining properties have been operated there. A more important field occurs about the headwaters of North Myrtle Creek and some of its tributaries. Placer-mining has been carried on there for years and with quite a satisfactory yield. In the vicinity the basic granular rocks are traversed (as so commonly elsewhere) by small quartz veins, and these are considered the source of the gold in the placers.

Veins occur in the basic igneous rocks of the Port Orford quadrangle, and assume some economic importance in the district in which head Sixes River, and Salmon and Johnson Creeks, and in a

few other places. These deposits are described with some detail in the text of the Port Orford folio. In general, they may be characterized as quartz veins—more rarely calcite-bearing—carrying some gold, and frequently stained by iron oxides or iron and manganese oxides. The less oxidized portions carry pyrites—in some cases a little galena and arsenopyrite. They occur chiefly in the granular intrusives, but are sometimes found in the sedimentary rocks—slates and sandstones. Occasionally they are associated with serpentine or dacite.

Economically more important have been the placer mines of this region, which have been worked since the early fifties. The chief areas on the Port Orford quadrangle are along Sixes River and the creeks above mentioned, corresponding closely to the distribution of the best-developed veins in the Dillard and the associated intrusives. It seems quite reasonable, therefore, to consider the gold as derived from these formations.

Effects of structure.—The minor economic importance of the auriferous veins associated with the Dillard and its related intrusives, is in large measure dependent on the character of the earth movements to which these rock masses have been subjected. While the changes they have undergone have been considerable, they have not been of such a character as to favor the production of great lodes. Instead of great fissures, there are innumerable fractures and faults of minute, small, and medium proportions, very local crushing, schistification, or slate production. Minute veinlets and small veins are therefore common. Rarely, however, does a vein maintain a uniform trend or even its existence for any great distance, and the various irregular small veins and "stringers" cannot be grouped into systems with regular attitudes. The mapping shows that intrusive dikes and masses exhibit the same characteristics. The only regularity to be observed in the mapping seems to have been brought about by the post-Cretaceous foldings which affected all the formations together.

If the quartz-diorites shall later be shown to be older than the Dillard, it may follow that some of the above deposits are pre-Dillard.

Copper.—Copper prospects have been found along the ridge near Dodson Mountain southeast of Roseburg. The metal occurs in chalcopyrite and malachite, in disseminated grains or bunches in

both the gabbro and serpentine. While some prospecting work has been carried on, no actual mine has yet been developed.

Nickel.—A considerable development of nickel silicate ores has taken place in the serpentine a few miles west of Riddles. This is part of the serpentine belt which extends through the Roseburg quadrangle continuously for over twelve miles, commencing near Dodson Mountain, where the above-mentioned copper prospects occur. There is strong evidence to prove that the nickel in these deposits was secondarily concentrated from the olivines of the serpentine.[1] Nickel in small quantity is a normal constituent of all the serpentines associated with the Dillard.

Chrome iron.—Chrome iron occurs in, or closely associated with, the serpentines at various places, either as disseminated grains or as masses, sometimes of large size. Several deposits occur west of Riddles in the same hills where the nickel is found.

Platinum.—The vicinity of the Klamath Mountains is a well-known American locality for platinum and iridosmine. According to Diller, these materials have been found in noteworthy proportions in the placer mines along Sixes River, being equal to 5 per cent. or more of the gold content. While the platinum has not been found in its original matrix, we may, from the position of the placers, conclude that it is derived from some of the formations that we have under consideration, and by analogy with other occurrences it may be referred to the serpentines.

Limestone.—The Whitsett limestone lentils are of sufficient purity to yield a good lime, and have been more or less used for that purpose. Certain parts have yielded variegated marbles which were cut in slabs and polished; but at present these are not being worked.

Sandstones and cherts.—Despite their superior lithification, the Dillard sandstones are so crushed and irregularly veined and fractured—especially those which have experienced the greater amount of cementation—that they are only occasionally suitable for quarrying or for the purposes of building. Cherts, such as occur here, have in other parts of the coast proved excellent road metal, but the development of this part of the country has not yet produced a demand for good macadamized roads.

[1] See, further, Clarke, "Some Nickel Ores from Oregon," *American Journal of Science*, 3d series, Vol. XXXV, pp. 483–88.

AREAL DISTRIBUTION IN THE REGION STUDIED

General method of determination.—The writer has determined the distribution of the Dillard and the Myrtle over considerable areas by actual field studies. In certain areas not visited, but which have been mapped and described in the various folios, the relative distribution may be approximately arrived at from an interpretation of the mapping and descriptions by means of the characteristic features which have been described above for each set of formations. The exposition of these field relations is probably best made by considering the folios seriatim as published by the Geological Survey, and indicating which of the areas there mapped as the "Myrtle formation" are occupied by the formations of the Dillard series, and which by the members of the Myrtle group, at the same time referring to their occurrence in neighboring, but as yet unmapped, areas.

THE INTERIOR QUADRANGLES

General distribution in Roseburg quadrangle.—If one turn to the "Historical Geology Sheet" of the Roseburg folio he will see that these formations occur only in the southern half of the quadrangle. The sedimentary rocks occur as three main areas, elongated in a northeast-southwest direction. The northernmost or largest may be called the Dillard area from the village of that name situated in its midst; the second may be referred to as the Myrtle Creek area, and the southernmost, in the southeast corner of the quadrangle, as the Days Creek area, for obvious reasons. There are also a number of small disconnected patches.

The Dillard area.—A large part of the Dillard area was studied by the writer, with the result that everywhere formations characteristic of the Dillard series were found, while no representative of the Myrtle group was recognized. It is probable that this whole area belongs to the lower series, although a more complete study may show subordinate patches or infoldings of the lower members of the Myrtle group. All of the members of the sedimentary series, all of the main types of igneous rocks, and the peculiar schists, described as characteristic of the Dillard series, occur within this area. The Whitsett foraminiferal limestone lentils crop out at intervals from about four miles directly east of Dillard to the northeast extremity of the area.

The Dillard area extends southwest beyond the limits of the map, into the vicinity of Olalla, and finally passes under the later rocks of the Coast Range. On the north also it is limited by the Eocene sediments and volcanics. In common with all the other pre-Tertiary rocks of this and the Riddles quadrangle, the Dillard series and its associated igneous rocks are bounded on the east by the lavas and tuffs of the Cascade Range, which, in the same direction, are followed by the lavas, etc., of the interior plateau region. The area under consideration is the most northern exposure of the Dillard series known.

The structure of the Dillard area cannot be definitely stated, except that the rocks have a general northeast-southwest strike, which, however, is locally varied without limit. In the section D-D of the Roseburg folio, across the strike of the series, it is represented as a succession of folds—three synclines and two anticlines—the whole forming a sort of synclinorium. The section C-C, six or seven miles farther northeast, represents the structure as monoclinal with a northwest dip. No suggestion is offered as to the manner in which the one structure passes into the other.

The Myrtle Creek area.—In contrast with the Dillard area, the Myrtle Creek area is made up almost entirely of the members of the Myrtle group. These occupy all of the area included in the Roseburg quadrangle except a small patch in the upper northeast corner near the head of Bilger Creek. In that corner the characteristic light gray, highly cemented, veined sandstones of the Dillard series occur, with irregular and indefinite structure; and, nearby, the regularly bedded, comparatively unaltered, fossiliferous shales and other members of the Myrtle group. The actual contact between the sedimentary members of the two groups was not observed, but they were exposed within 100 yards of each other.

The Myrtle Creek area has, in general, a simple structure. The strata strike and the area extends in a northeast-southwest direction, and the rocks have been folded into a simple syncline about three miles across as now exposed. This synclinal structure extends throughout the area that is included in the Roseburg quadrangle, and continues to the southwest into the Riddles quadrangle. It there lies on both sides of the Umpqua River, which it leaves in the

vicinity of Riddles, and continues along Cow Creek. The writer traced it a few miles above Riddles on Cow Creek, but cannot state how far it extends in that direction.

The boundary contacts of the Myrtle Creek area are generally formed by a heavy conglomerate which usually rests directly on the pre-Myrtle intrusives, sometimes on the Dillard sediments. This conglomerate, along the northwest border of the area, is very thick—over 1,000 feet near the village of Myrtle Creek. It was traced by the writer continuously for over fourteen miles, and, according to Mr. Will Q. Brown,[1] is traceable without a break for over twenty miles. The basal conglomerate is also found on the southeast border of the area, where it is considerably thinner, and was studied only along four or five miles of contact, about three of the miles near Myrtle Creek, and the rest near Riddles. The lithologic characters of this conglomerate have been described in a previous section.[2]

At the northeast extremity of the Myrtle Creek area the conglomerate does not appear to be basal, but is underlain by Aucella-bearing shales (and very thin-bedded sandstone) which rest directly on the igneous rocks without noticeable alteration. This may mean that the syncline represents a trough of deposition, and that along the median line the conglomerate may not be strictly basal, but may be underlain by a deposit of shale, which has been overlapped along the sides by the later deposited conglomerate.

As noted earlier, conglomerates occur at various horizons in the Myrtle group, and may some day serve to delimit its various members, as, for example, the beds corresponding to the Horsetown from those corresponding to the Knoxville. No attempt so to use them has been possible in this investigation.

Smaller areas between the Dillard and Myrtle Creek areas.—Between the Dillard and the Myrtle Creek areas are mapped several smaller ones. The largest of these is about six and one-half miles long, and from about a quarter to a third of a mile wide. It lies partly in the "metagabbro," and partly between the serpentine and the other intrusive. It is also penetrated by small dikes of serpentine and by small masses of greenstone (chiefly intrusive basalts) not shown on the map. Associated with this area at one point is a patch

[1] Quoted by Becker, *Geological Society of America Bulletin*, Vol. II (1891), p. 203.

[2] See p. 534.

of the same nature, about three-quarters of a square mile in area, entirely inclosed in the serpentine, and apparently torn from the main area by the act of serpentine intrusion. Another small area lies entirely in the "metagabbro" along the Umpqua River (near the railroad), and is also associated with serpentine dikes not shown on the map.

All of these smaller areas are composed of Dillard sandstone, etc., which show their characteristics very distinctly, and are, in general, considerably altered. The form of each of these areas is rather long and narrow, and it can be distinctly seen in the field that they do not merely lie on the intrusives, but in them as included or partially submerged masses.

Contrast between close-lying areas of Myrtle and Dillard.—The strong contrast and abrupt change (i. e., not gradational) between the Myrtle and the Dillard can be well observed on ascending the ridge a few miles southwest of Dodson Mountain, going up from Bilger Creek so as to reach the Dillard areas as close to the Myrtle as possible. After leaving the Myrtle shales, one passes onto the basal conglomerates which are regularly bedded with a very uniform strike for miles, along the higher flanks of the ridge. Leaving these conglomerates, one passes onto the serpentine, and then shortly onto the disconnected area of Dillard. This shows no trace of conglomerate, but is chiefly of hard gray sandstone, well cemented, and not infrequently traversed by quartz veins and stringers. The strike is irregular. At one point near the border, it is perpendicular to the regular strike of the Myrtle, which is only some 200 or 300 yards distant across the serpentine. The characters of the Dillard would seem to be largely dependent on its intrusion, while in the Myrtle nothing that could be definitely referred to intrusive action was observed.

To the south, in the vicinity of Canyonville, sedimentary rocks of the Dillard group are found on the southeast side of the Myrtle Creek syncline. Their extent was not determined, nor their contact with the Myrtle studied.

The Days Creek area.—The writer did not visit the Days Creek area, but from the statement in the text of the Roseburg folio, which refers to the Horsetown horizon, that "fossils of this horizon have been found . . . . throughout the area along Days Creek," we may infer that it is entirely Myrtle, perhaps all Upper Myrtle.

THE COASTAL QUADRANGLES

The Coos Bay quadrangle.—On the Coos Bay quadrangle there are two main areas mapped as "Myrtle formation," both of which are in the most southern part of the quadrangle, besides some disconnected rocks and small bunches, along the coast near Bandon. These are apparently all Dillard. The writer studied the large area in the vicinity of Myrtle Point, and found it made up entirely of typical Dillard formations. No trace of the Myrtle group was found. That all of the areas are Dillard, with no Myrtle, may be inferred from the descriptions and mapping of the folio. No fossils (other than protozoan) were found, and in every small area, radiolarian cherts, greenstones, glaucophane schists, alone or together, are distinctly in evidence, while the semi-metamorphic sandstones make up the main mass.

The Port Orford quadrangle.—Considerable areas have been mapped as the "Myrtle formation" in the Port Orford quadrangle. The writer found time to examine only the northeastern portion within about ten miles of its northern boundary. All of that portion examined is distinctly Dillard, which is covered directly by the Arago (Eocene) without the intervention of the Myrtle. The unconformity between these two formations is well seen on Salmon Creek, about a half-mile above its junction with the South Fork of the Coquille River. The creek there flows on the contact, and the Eocene beds on the east dip off regularly (at about 31° E.) from the highly inclined (74° E. and over) and irregular Dillard beds. Pebbly layers in the Eocene sandstones carry detritus derived from the neighboring Dillard.

Judging from the abundance of basalt, chert, small serpentine dikes, and masses of amphibole schists, it may be inferred that most, if not all, of the northern part of the Port Orford quadrangle is Dillard, as far down perhaps as Sixes River. A considerable area below this, through the midst of which runs Elk River, appears, on the map, remarkably free from these diagnostic rock types, which, however, again appear in part in the southwest corner, and in a north-south belt just east of Iron Mountain.

According to the text of the Port Orford folio, Horsetown and Upper Knoxville fossils are found in the Rogue River section in the

southeast corner of the quadrangle. This section is estimated as 1,500 feet thick, and is said to be made up of "much shale mixed with the relatively thin-bedded sandstone, and although the rocks are highly tilted, their stratification is well preserved." Furthermore, "the base of the series on Rogue River below Agnes is a heavy conglomerate, best exposed perhaps in a prominent bluff near the trail one and one-half miles northwest of Agnes. *A. crassicollis*, which is the later form, characterizes this portion of the section where it is separated from the Colebrooke schist by a belt of serpentine." This is evidently a section of the Myrtle group, and we may infer a gradually depressed sea bottom as the Upper Knoxville horizon has overlapped the lower, and lies directly on the pre-Myrtle rocks with a basal conglomerate.

The most extensive fossiliferous section described is on "Elk River, beginning to the east in Copper Mountain with large masses of conglomerate and sandstone overlying shales and sandstones, the whole containing *A. piochii*." Farther down the river, "shales and sandstones are well exposed and contain numerous fossils in place." These are referred to the Upper Knoxville by T. W. Stanton. The Elk River section is, therefore, as already inferred from inspection of the map, chiefly, if not wholly, of the Myrtle group.

In the northwestern part of the quadrangle occurs an outlier of the Klamath Mountains schists, upon which the Myrtle group lies, "and the basal portion is a conglomerate containing many fragments of the schist. The conglomerate commonly contains *Aucella crassicollis*." We had thus repeated the phenomena of overlap of the Upper Knoxville horizon over the lower and onto the schists, as already described for the Rogue River section, which is about twenty-five miles distant.

THE DISCONTINUITY OF THE DILLARD AND THE MYRTLE

Where the exposures of the Myrtle group have been observed in close proximity to those of the Dillard series, there was found no gradation from the lower to the higher formations, but a distinct break in lithologic character and structure. The evidence already presented is to the effect that this break represents a period during which many events were brought to pass which we may believe required

considerable time for their accomplishment. To bring this more distinctly before the mind, we may summarize the more important events connected with this interval.

1. There were at least three distinct periods of igneous activity, in each of which rocks of more or less variety and in considerable abundance were produced. These three periods have not been found to overlap, but everywhere have a definite order of eruption over large areas, and probably represent distinct intervals of time.

If these three groups are in any way genetically connected, they must represent deep-seated and general differentiation, and we may note that the basic (to intermediate) group appeared first and in greatest abundance, followed later by the ultrabasic and the comparatively acid groups, apparently in the order named. Within each group there has been distinct and often considerable differentiation, the products being related in lithological characters and by gradational forms. Compared with the hypothetical differentiation between the groups, this intra-group differentiation is more local, less complete, more evident, and does not make the same time demand upon the period under discussion.

The basic series may have been in part contemporaneous with the deposition of the members of the Dillard series.

2. The degree of lithification of the Dillard, which is one of its most marked characteristics, is considerably higher than that of the Myrtle. The Dillard type of alteration, the cementation and quartz-veining, could only have been produced at some depth, and the abrupt change on passing to the Myrtle, and the absence of comparable alteration in the lowest Myrtle, show not only that the alteration was pre-Myrtle, but that the upper unaltered layers of the Dillard had been removed before the deposition of the basal beds of the Myrtle group.

3. The general strike and the elongation of the Dillard area are the same as those of the Myrtle Creek area. This is apparently due to the orogenic disturbances in post-Myrtle time (including pre-Eocene and post-Eocene movements), which affected both groups in the same way. But the marked irregularities of attitude in the Dillard near the base of the Myrtle, and its divergence from the latter within short distances at places where, within the Myrtle, the

structural uniformity may be traced for miles, indicate crustal disturbances and folding in the Dillard series before the deposition of the Myrtle.

A further argument for such physical activities during the Dillard-Myrtle interval may be gathered from a consideration of the fracturing and crushing produced. These are characteristically present in the Dillard exposures and are often excessive. In the Myrtle, however, they are only locally in evidence to any marked degree, as, for example, along an occasional fault plane or where the shales have been folded against hard or massive formations. In the Dillard we may connect this fracturing and crushing in part with the various intrusions, in part with the swelling and moving of the solidified serpentines, but a certain amount can be referred only to crustal movement that was post-Dillard and pre-Myrtle.

We may conclude, therefore, that the Myrtle group was deposited unconformably upon the Dillard series after an interval of varied igneous activity, earth movement, and erosion.

COMPARISON WITH THE STANDARD CALIFORNIA TYPE FORMATIONS

THE MYRTLE GROUP

Identity with the Shasta.—In describing the paleontologic limits[1] and characters[2] of the Myrtle group, and its nomenclature,[3] it has been shown that it corresponds to the Shasta group of California, and that the succession of horizons—Lower Knoxville group, Upper Knoxville, Horsetown—is the same as in the Shasta group, and characterized by the same fossils. It remains to be pointed out that the lithological characteristics are identical, and, considering its distribution in connection with the known distribution of the Shasta group, which is so strongly developed over large areas in northern California, we may safely conclude that it is strictly Shasta, and was deposited in the same sea, during the same period, and under the same conditions of erosion and deposition as the Shasta of California.

THE DILLARD SERIES

General characteristics of the Franciscan.—One familiar with California Coast Range geology will already have anticipated the

[1] See p. 519. [2] See p. 522. [3] See p. 520.

correlation of the Dillard with the Franciscan series. The Franciscan is a thick series of rock formations which is widely scattered over the coastal portion of California and which bears the record of an important part of Californian geological history. Its stratigraphic boundaries so far known are the marked unconformity at its summit, separating it from the base of the Knoxville (zone of the *Aucella piochi*), and the striking unconformity at its base separating it from the older holocrystalline terranes (crystalline limestones, schists, and Coast Range granites, etc.). Lithologically it is characterized by its massive, arkose sandstones and radiolarian cherts—besides which shales, conglomerates, and foraminiferal limestones occur—and by its degree of lithification, which is, as far as known, unique in the coast region. This latter alone separates it from all later and earlier formations with which it has yet been found associated. It is also characterized by being intersected by an abundance of igneous rocks—greenstones, diabases, etc.: serpentines and gabbros; and more acid porphyritic types—and by the presence of glaucophane and related schists. Paleontologically it is characterized by a general absence of fossils, those which have been found leaving the age indefinitely determined, but indicating, in a general way, that they may belong anywhere from the Lower Cretaceous to the Jurassic inclusive.

Identity with the Franciscan.—In all of its characteristics and peculiarities the Dillard series is practically identical with the Franciscan,[1] and it fits into the same stratigraphic position, and it may be concisely defined by the brief description of the preceding paragraph. It was evidently formed under the same peculiar series of physical conditions, has been subjected to very similar series of igneous eruptions, to practically the same degree of lithification, and to about the same amount and character of disturbance and erosion.

The Whitsett limestone fossils.—The two fossils reported by Stanton as occurring in the limestone of the Roseburg quadrangle

[1] For further comparison of the characteristics and peculiarities of the Dillard with those of the Franciscan, reference may be made to the description of the Franciscan type locality by Professor A. C. Lawson, U. S. Geological Survey, *Fifteenth Annual Report* (1895), pp. 415–35; and to the description of the San Luis quadrangle by Dr. H. W. Fairbanks (U. S. Geological Survey, *Geologic Atlas of the United States*, Folio No. 101), who has mapped a considerable area of Franciscan in the southern Coast Ranges of California, about 8° of latitude south of the Dillard area, but in which the peculiarities are closely the same throughout.

cannot be accepted as throwing much light on the definite age of the Franciscan. The forms were rather imperfect. The *Hoplites* was said to be identical with or near to *H. dilleri* which has been found in the Knoxville. Whether the Franciscan includes representatives of the Lower Cretaceous, Jurassic, or (and) intermediate time, there is no reason why some forms should not range from the Franciscan into the Knoxville with the same, or with but slightly different, characters. Indeed, considering that the Mariposa beds of the Sierra Nevada, now for some time accepted as Jurassic, were believed by White,[1] in the eighties, to be contemporaneous with the Knoxville on paleontological evidence, and both were referred to the Lower Cretaceous by Becker,[2] we have good reason to expect that some faunal similarities would exist.

In connection with the *Opis californica* found in the Whitsett limestone, it may be pointed out that an imperfect fossil from the base of the Franciscan on the northeast slope of Montana Mountain—part of the Franciscan type area—was also referred by Stanton to the genus *Opis*.[3]

In general, it may be added that, as several geologists have at times confused the Knoxville and the Franciscan in various localities, considering the latter a metamorphosed facies of the former, it is possible that certain "Knoxville" localities credited to some of the fossils are, in reality, Franciscan.

The Jurassic question.—At several localities in the region under discussion fossils have been found which have been referred to the Jurassic. At Bucks Peak, some miles southwest of the Roseburg quadrangle, a sandstone carries fossil leaves which have been referred to the Jurassic by Professor Fontaine; and, in the bed of Elk River in the Port Orford quadrangle, loose pieces of shale were found containing plants which he considers of the same age—Lower Oölite. The shales were not recognized in place. On Johnson Creek Diller found fragments of shale containing *Aucella*, which Stanton refers to the Upper Jurassic—Mariposa beds. According to Diller, "the Jurassic sediments closely resemble those of the Myrtle formation,

[1] U. S. Geological Survey, *Bulletin 15* (1885), pp. 24–26.

[2] U. S. Geological Survey, *Bulletin 19* (1885), pp. 18–20; also *Bulletin of the Geological Society of America*, Vol. II (1891), p. 206.

[3] U. S. Geological Survey, *Fifteenth Annual Report* (1895), p. 443.

and in the field they were not separated." The same is true of the Bucks Mountain locality, although the sandstones there are said to be "somewhat metamorphosed." The "Jurassic" shales of the Port Orford area are sometimes referred to as "slaty shales." This partially metamorphosed character, the association with the Dillard formation, and the fact that they could not in the field at any locality be separated in characters or appearance from the "Myrtle formation," would suggest that they are really Dillard, or that the Dillard (Franciscan) is, in part at least, Jurassic. It is possible, however, that these beds may lie stratigraphically (even unconformably) below the Franciscan, and a careful examination of the field to determine this point is desirable.

EXTENSION OF THE FRANCISCAN

The Dillard not only may be looked upon as a northern extension of the Franciscan, but is of particular interest as extending the area in which obtained *in toto* that congeries of peculiar conditions of sedimentation, life, vulcanism, and diastrophism which characterizes the Franciscan of central California. According to Fairbanks, to whom chiefly we are indebted for statements of the distribution of these Franciscan conditions, "the farthest point to which it can be traced southward is southern Santa Barbara County, where it disappears beneath the Cretaceous."[1] Furthermore, "the series has been recognized by the writer from central Santa Barbara County northwestward through the Coast Ranges to the Klamath Mountains. On the western slope of these mountains it has been traced to the Oregon line, and it undoubtedly extends farther."[2] The present investigation has extended the limit of the Franciscan about eighty-five miles farther north and beyond the Klamath Mountain group, and there it is found to pass under the Eocene sediments at the edge of an extensive Tertiary province. It is possible that the Franciscan conditions will not be found north of the present boundary, but even with this limit, the known extent of this unique sequence of conditions —about 600 miles along the coast—is quite remarkable.

[1] *Bulletin of the Geological Society of America*, Vol. VI (1895), p. 83. It may be remarked that by "Cretaceous" Fairbanks means the Shasta-Chico series. He considers the Franciscan entirely pre-Cretaceous.

[2] *Journal of Geology*, Vol. III (1895), p. 416.

THE SHASTA (LOWER CRETACEOUS) SEA

It has been shown that the Myrtle group terminates to the north (in the Myrtle Creek area) against a Franciscan territory, with a conglomerate over a thousand feet thick at its base. This conglomerate contains abundant Franciscan detritus. Some of the chert may possibly be derived from pre-Franciscan terranes, but this remains to be proved. Almost nothing that must be referred to the pre-Franciscan was found. No pebble of any of the older schists was observed, and only a very rare one of granite. As this heavy conglomerate can be traced for over twenty miles on the northern limit of the Myrtle, and is thinner on the south flank of the syncline, it may be inferred that the shore-line of the early Knoxville sea was not far distant, with land, made up of Franciscan surface exposures to the north.

The occurrence of Horsetown overlapping the Knoxville and resting unconformably, often with basal conglomerate, directly on the pre-Knoxville terranes, indicates a subsidence and transgression of the sea during the Shasta period. This general relation has been pointed out by Diller, who has shown that in the northern California field, "everywhere beyond the limit of the Knoxville beds, the Horsetown beds rest with a marked unconformity, directly on the metamorphics."[1] He has even been to able show, by the aid of fossils, that the upper part of the Horsetown overlaps the lower.

As the Shasta in the Oregon region here discussed is limited by the Klamath Mountains on the south, against whose older terranes it rests with basal conglomerates, we may conclude that the Knoxville sea entered this region as an arm elongated in an east-west direction, and that with the passing of time the sea transgressed farther and farther, the arm becoming broader, especially toward the south and southeast, until it probably, as also believed by Diller, united with the waters encroaching from south across northern California around the other side of the Klamath Mountains.

The present investigation has, in particular, made it possible to trace more closely the nature and boundaries of the Myrtle arm of the Shasta sea, and to infer the nature of the rocks which formed the coast line.

[1] Diller and Stanton, *Bulletin of the Geological Society of America*, Vol. IV (1893), p. 214.

THE BOUNDARY OF THE KLAMATH MOUNTAINS

In the vicinity of the Klamath River (in northwestern California) occurs a large area of crystalline rocks which bear, in many ways, resemblance to those of the Sierra Nevada, and which created considerable doubt, when first studied, as to whether this area should be considered part of the Coast Ranges, which topographic continuity would suggest, or part of the Sierra Nevada, to which it appeared geologically related. The Gordian knot was cut by giving it the name Klamath Mountains, and[1] separating it from the Oregon Coast Range on the north, the Cascade Range on the northeast, the Sierra Nevada on the southeast, and the California Coast Ranges on the south and southwest. As this region has a geological individuality, and as the multiplicity and vagueness of local names for its parts tended to considerable confusion, it was a decided step in advance to characterize this province, delimit it, and give it a comprehensive name. For following up this idea and working out the details we are chiefly indebted to Mr. Diller.

The present investigation has shown that in southwestern Oregon, down to about the Rogue River, the geological formation, structures, and other conditions are such as prevail in the California Coast Ranges. The Franciscan series is particularly well developed to the southwest and south of the Klamath Mountains in Humboldt, Mendocino, and Lake Counties (lat. 41°–39° N.), and beyond, in all respects like the Franciscan (Dillard) to the north of the Klamath Mountains in Oregon. It would seem most consistent, therefore, and satisfactory, to omit the Franciscan and Shasta areas on the north from the territory to be included under the title of Klamath Mountains. This would remove the northwest and the northeast lobes as represented on the various maps of the Klamath Mountains,[2] and make the boundary cut across toward the west from near Jacksonville and follow close to the Rogue River until a short distance below the mouth of the Illinois, then west to the coast. In other words, the Klamath Mountains would be that general uplifted region characterized by a nucleus of metamorphic (and associated igneous)

[1] See Powell, *Physiographic Regions of the United States* (1895), p. 96 (Monograph, National Geographical Society).

[2] E. g., that published in *Bulletin 196* (Plate I) of the U. S. Geological Survey.

rocks.[1] The occurrence of metamorphic outliers—such as the Grouslous Mountain area of the Port Orford quadrangle—and of small areas of unmetamorphosed inliers, cause but slight difficulty, which, however, exists whatever criteria of discrimination be used. It may be added that the two lobes which it seems logical on geological grounds to detach from the Klamath Mountains, are no more related to them topographically than other neighboring parts of the Coast Ranges.

NOMENCLATURE

In approaching this field of study, the term "Myrtle formation" was found applied to a number of formations which are naturally separable into two distinct groups, to the upper of which alone the term "Myrtle," as stratigraphically defined by its author, is applicable. It seemed best, for the development of the subject in this paper, to use a local term—"Dillard," recalling what is perhaps the most typical area in the region—for the lower series as the complement of the existent local term, "Myrtle."

The writer, however, is not in sympathy with the unnecessary multiplying of local names. To correlate, to trace general conditions and relationships, are undoubtedly among the most important aims of science, and multiplicity of terms—especially synonyms—tends to obscure and conceal such relationships. In particular, in the case of geological formations and groups it would seem highly desirable that those which the best evidence indicates as contemporaneous, and which were ushered in and brought to a close by the same sets of physical changes, should be designated by the same name. This is especially true when they occupy the same relative position in closely similar stratigraphic sequences and were formed under the same general physical conditions. The rocks of the Myrtle group, for example, have the same characteristic fossils, and the same stratigraphic position and range, as the Shasta group of California. They occupy corresponding positions in remarkably similar stratigraphic sequences, and their upper and lower limits were apparently determined by the same great diastrophic movements. Furthermore, the character of sedimentation is the same, and the distribution is such

[1] The term "Klamath Mountains" has been used in this sense throughout this paper.

that they are believed to have been deposited under similar conditions in the same sea during the same period. According to the above principles, therefore, they should be given the same name.

That there is another point of view, however, is shown by the fact that the author of the term "Myrtle formation" has used it in the maps and texts of three different folios, and in other papers, with the distinct understanding and belief for which he presents evidence, that the rocks so designated were formed in the same sea, at the same period, and have the same stratigraphic limits and characteristic fossils as the Shasta. No reason has been given, as far as known, for coining and using the local synonym.

In the writer's opinion, therefore, the best and most practical interests of science would be served, in the present case, by referring to and mapping the formations under discussion as the Franciscan series and the Shasta group, respectively, of the Roseburg quadrangle, or of whatever quadrangle may be under consideration. If, however, for some reason or other, local terms may seem desirable for the Oregon field, it is believed that the names used in the above discussion represent natural groups, and have been sufficiently definitely defined to serve a useful purpose.

SUMMARY OF RESULTS

The rocks of southwestern Oregon which, in the Roseburg, the Coos Bay, and the Port Orford quadrangles have been mapped as the "Myrtle formation," and considered to represent a period of continuous sedimentation corresponding to the Cretaceous from the base of the Knoxville to (at least) the top of the Horsetown, inclusive, are divisible into two natural groups, which differ in their lithological and other characters, and which are separated by an unconformity representing a period of considerable geologic activity.

The older (Dillard) series is pre-Knoxville and of considerable thickness (not measured, but perhaps 8,000 to 10,000 feet), and gives evidence of a sea in which were characteristically developed radiolarian cherts in series of regularly recurring thin beds, alternating with a peculiar ferruginous shale; thick-bedded, arkose sandstones, almost entirely devoid of fossils; and occasionally a foraminiferal limestone. Less characteristic shales and conglomerates were also formed. These deposits were made in Franciscan time, when the

Coast Range region of California was largely under water, at least so far south as about latitude 34° 30′ N. This sea invaded the Oregon coast at least as far north as latitude 43° 15′ N.

Following the deposition of these beds—perhaps in part during it—at least three series of igneous rocks were intruded at separate intervals; a basic series (basalts, diabases, etc.); an ultrabasic series (serpentines, pyroxenites, gabbros); and an acid sodic series (dacites, andesites). There is also evidence of elevation of the Franciscan sediments to dry land, dislocation, fracturing, crushing, considerable cementation and veination, and, finally, a long period of erosion, which stripped the sediments from the granular intrusives over large areas. This whole course of events, of sedimentation, vulcanism, cementation, diastrophism, and erosion, follows closely, in sequence, characters, and intensity, the history of the corresponding time throughout the California Coast Range province, and extends the recognized limits of this province almost 100 miles, making the extreme length now known about 600 miles.

Following the period of erosion came another period of dominating subsidence, and the gradually transgressing sea, which deposited chiefly fine sediments with some sand and well-washed gravels, built up the upper (Myrtle) group of rocks, which reach the thickness of about 6,000 feet near Myrtle Creek. These are more or less fossiliferous and contemporaneous—probably continuous—with the Shasta group of California. The sea entered this Oregon region apparently as an arm elongated in an east-west direction, with its south shore against the Klamath Mountains and its north shore about the latitude of Roseburg. The land to the north showed chiefly Franciscan exposures; that to the south, both Franciscan and the earlier crystalline schists, etc. With the progress of Shasta time this arm broadened, and finally united with the gulf which was advancing over northern California around the other side of the Klamath Mountains, making of this mountain group an island, which may possibly have been finally submerged.

The glaucophane and associated schists of southern Oregon were formed during the same period as the similar schists in California (pre-Knoxville) and are associated with similar rocks of the same (Franciscan) series.

ARAPAHOE GLACIER IN 1905

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On August 30, 1904, H. F. Watts and the writer, for the purpose of ascertaining the rate of movement of Arapahoe Glacier, placed upon the ice ten zinc tablets, tying them accurately to bench marks on the granite walls and terminal moraine by triangulation and direct observation. No. 1 was placed 300 feet from the northeast edge of the ice; No. 1 to No. 2, 89 feet; No. 2 to No. 3, 51.7 feet; No. 3 to No. 4, 58.6 feet; No. 4 to No. 5, 65.4 feet; No. 5 to No. 6, 82.8 feet; No. 6 to No. 7, 84.4 feet; No. 7 to No. 8, 73.8 feet; No. 8 to No. 9, 97.2 feet; No. 9 to No. 10, 114.4 feet. On August 30, 1905, we again visited the place and made accurate measurements, ascertaining that No. 1 had moved 11.15 feet; No. 2, 11.9 feet; No. 3, 13 feet; No. 4, 15.9 feet; No. 5, 16.75 feet; No. 6, 18.5 feet; No. 7, 20.6 feet; No. 8, 20.45 feet; No. 9, 21.7 feet; No. 10, 27.7 feet.

We have found each year, since the original survey in 1902, unmistakable evidence of shrinkage all along the lateral margins near where they curve into the terminal moraine, and along the terminus, particularly where the effects of erosion by surface drainage is greatest; but all this time the center of the ice-tongue has shown no shrinkage, either horizontally or vertically. Along the northeast margin the ice has shrunk away from the moraine about four feet since last year, all observations being made at the same time each year.

The snow-line on the ice, which had moved forward a long way during 1903 and 1904, has suddenly receded this year so far that the ice is bare nearly to the Bergschrund, as in 1902. A detailed examination of the summary of weather records of the three nearest United States Weather Bureau stations throws no light upon the cause of this sudden change. Comparison of photographs taken with the same lens at the same time of the year in 1904 and 1905 shows but little change in the extent of the snowbanks of the region, some having decreased in size, a few increased, but mostly stationary or slightly smaller.

PAPERS READ AT THE SUMMER MEETING OF SECTION E, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, AT SYRACUSE, N. Y., JULY 19–22

"Stratigraphic and Economic Geology of the Syracuse Region," T. C. Hopkins.

"Glaciation of North America, with Particular Reference to the Effects of the Ice Sheet in Central New York," H. L. Fairchild.

"The Great Lakes in Their Relation to Local Geology," Frank B. Taylor.

"Sudbury Basin Shorelines," F. P. Gulliver.

"Some New Problems in Glaciology," H. L. Fairchild.

"The Physical Character and History of Some New York Formations," A. W. Grabau.

"The Burrow Origin of Arthrophycus and Daedalus (Vexillum)," C. J. Sarle.

"The Occurrence of Glacial Epochs in Paleozoic Time," David White.

"The Age of the Wise and Harlan Formations of Southwestern Virignia," David White.

"The Western Sierra Madre of the State of Chihuahua, Mexico," E. O. Hovey.

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